ASSESSMENT

OF RECENT CHANGES IN THE

EXPLORER PROGRAM

Panel to Review the Explorer Program

Space Studies Board

Commission on Physical Sciences, Mathematics, and Applications

National Research Council

December 1996

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PANEL TO REVIEW THE EXPLORER PROGRAM

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FOREWORD

Explorer 1 was the third man-made satellite to orbit Earth. Launched on February 1, 1958, four months after Sputnik 1, it made spaceflight history and scientific history: it discovered the Van Allen radiation belts.

Since then, the Explorer program has been an extraordinarily productive component of space physics and astrophysics. As a "level-of-effort" program, it has provided reasonably predictable and continuous funding to support moderate-sized missions that survive rigorous peer review. This very successful model is now being emulated in the planetary and Earth sciences through the Discovery and Earth System Science Pathfinder programs.

Of course, much has changed in the 40 years since Explorer 1. Vast increases in technical capability have only been outstripped by the rising scientific expectations of an increasingly sophisticated and diverse research community. The three key players, NASA, industry, and universities, have all experienced profound alterations. The shuttle-dominated 1980s were a fallow period for Explorers. More recently, NASA has made major changes to the program to recapture the scientific vitality of its earlier decades.

This study assesses these recent changes to the Explorer program and recommends modest mid-course corrections to help it better achieve its objectives. The panel's strong endorsement of those objectives and its conclusion that the program can be of outstanding scientific value echoes and reinforces similar findings of numerous previous Space Studies Board reports.

Claude R. Canizares
Chair
Space Studies Board

PREFACE

On May 13, 1996, NASA Associate Administrator for Space Science Wesley T. Huntress requested the Space Studies Board to make a "fast turn-around assessment" of the Explorer program. The background and objectives for the study expressed in his request were the following:

> As NASA Space Science evolves towards lower-cost missions and smaller and more agile flight missions, it is NASA's intent to evolve the Explorer and Discovery program lines to increase the available flight opportunities for the Space Science community. In order to achieve this, the Explorer program was restructured toward lower-cost missions by reconfiguring the Far Ultraviolet Spectroscopic Explorer (FUSE) mission and replacing the Delta-class Explorer line with the mid-sized (MIDEX) and the university-class (UNEX) programs. A second step towards this objective is that missions in these level-of-effort programs should be defined and developed by the Space Science community itself instead of by the Agency. This concept, in which the Principal Investigator (PI) proposes both the payload to complete a science investigation as well as the spacecraft itself as an integrated package, was tested and established in the Discovery program of small planetary missions and embodied in the "PI mode" option included in the first MIDEX Announcement of Opportunity. In pursuing this approach, the Office of Space Science considers the Discovery program as a model for the direction in which the Explorer mission line is to evolve. A third step is to achieve effective competition across the entire Space Science community and to ensure an equitable and fair evaluation process.
>
> In order to assist the Office of Space Science in meeting these objectives, the National Research Council is requested to conduct a fast turn-around assessment of the Explorer program including recent selections as follows:

1. How do the current management arrangement for Explorer and the procedures for selecting Explorer missions affect:

   - Research community engagement in the program
   - Involvement of NASA field centers
   - Effective utilization of the aerospace industry
   - Overall scientific effectiveness of the program

2. How do the Explorer program management arrangements and mission selection procedures compare with the Discovery line, and what are the best features of each?

3. What, if any, improvements could be made to management arrangements and mission selection procedures in the Explorer program?

A small group, the Panel to Review the Explorer Program, was assembled to consider this charge. It consisted of members with balanced expertise and experience in the following areas: space physics,

space astronomy, the Discovery program, aerospace industry, and project management. Since the space physics and space astronomy members were potential Explorer investigators (in fact, two of them are currently investigators, one for an earlier Explorer and one for a SMEX instrument), a frank and thorough disclosure of interests by all members and the broad representation on the panel served to ensure that deliberations were balanced. On one occasion, a panel member with specific interest in future international aspects of the Explorer program was excused from related discussions and informal polling.

The panel met under the auspices of the National Research Council on September 12, 13, and 14, 1996, to hear presentations on the Explorer and Discovery programs and Headquarters' perceptions of these programs (Appendix A lists the meeting participants), and to discuss them with Associate Administrator Huntress. The panel achieved consensus on key issues at the end of this meeting, and the report was finalized during a telephone conference on October 14.

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EXECUTIVE SUMMARY

Since the 1960s, the Explorer program at the Goddard Space Flight Center (GSFC) has been of crucial importance for the disciplines of space physics and space astronomy. Level-of-effort funding for the Explorer program enabled these disciplines to develop many relatively small, Earth- and moon-orbiting missions that allowed these disciplines to progress, to develop new technologies and instruments, and to foster a substantial body of talented investigators. In the 1980s, Explorer began to depart from its small-and-frequent character and to put its resources into a few larger missions; for example, the X-ray Timing Explorer (XTE) and the Far-Ultraviolet Spectroscopic Explorer (FUSE) each cost in the $200 million range. As the 1990s progressed, however, budget and scientific community pressure mounted for smaller and more frequent missions, forcing a reappraisal of NASA's general approach to space science missions.

In 1994, the downscoping and restructuring of the FUSE mission signaled the end of the Delta-class Explorers. The new Explorer program consisted of a Mid-class Explorer (MIDEX; capped at $70 million per mission), the existing Small Explorer (SMEX; capped at $35 million per mission), and the University Explorer (UNEX; capped at $5 million). The cap refers to the charge to the Explorer budget line. In March 1995, NASA conducted the first competition for the MIDEX program, with selections made the following spring.

Following this first round of MIDEX selections, NASA's Office of Space Science requested that the Space Studies Board assess the solicitation and selection process recently concluded in terms of the program's objectives to optimize science value through a competitive, community-based program of frequent flight opportunities in astronomy and space physics. The Discovery program for solar system exploration was identified as a model for future evolution of the Explorer program. In order to carry out the assessment, which was to consider involvement of the science community, NASA centers, and industry as well as overall scientific effectiveness, the Board established the Panel to Review the Explorer Program. The panel met on September 12-14 to be briefed on the program to date and to evaluate its progress in the terms requested. Following are the findings of the panel and a number of recommendations based on these findings and information provided.

General Finding. The panel believes that most of the perceived problems brought to light after the first MIDEX AO were due to the "dual mode option"[1] and the lack of full cost accounting for government contributions. In addition, debriefing of unsuccessful proposal teams was not adequate. While the AO and the selection process both need improvement, and while interaction with the science community also needs to be strengthened, the panel believes that the program is now on the right path and that the new Explorer program should be excellent if properly administered. The perception will probably continue that GSFC and its scientists have an advantage, but the panel is satisfied that the Explorer program management is addressing this issue and that elimination of the recognized flaws will bring about a level playing field for both scientists and industry. Given time and continuing effort, it is the belief of the panel that the astronomy and space physics communities will strongly support the program.

[1]The first MIDEX Announcement of Opportunity (AO), released on March 27, 1995, offered two options for structuring the management approach of a proposal: a more traditional approach in which a flight project would be managed by GSFC, with Principal Investigator (PI) responsibility limited to instrumentation ("NASA-provided spacecraft mode"), and a Discovery-like approach in which a PI would assume total responsibility for the mission, possibly including delegation of project management functions to industry or to a NASA field center ("PI mode").

Finding 1. The panel supports use of the "PI mode" by NASA. It brings new vigor to the program at a time when diminishing opportunities could lead to disillusionment amongst the science community. It is an open process that appears to be intrinsically fair. It has exposed a reservoir of ideas for focused science under a cost cap.

Finding 2. The panel believes that the new Explorer program cannot succeed without a high level of support by the science community. In the first (1995) MIDEX solicitation the most readily avoidable errors were failure to consult adequately with the community in the development of the AO and failure to undertake face-to-face debriefings with investigators after the process. These management errors have led to problems with the science community, but they can be resolved through a thoughtful effort in developing future AOs, and again after selection has taken place.

Finding 3. The panel understands from presentations made to it that the "dual mode option" will be eliminated from future Explorer AOs and that the "PI mode" will be the *only* management approach allowed. The panel endorses this decision.

Finding 4. The panel concludes that the new Explorer program at GSFC is well managed and is aggressively moving to fully support the "PI mode" management approach. This includes a move to full cost accounting for government contributions.

Finding 5. The panel believes that the restructured Explorer program can be of outstanding value not only for the science performed, but also for its role in maintaining U.S. scientific capabilities in an important area of space science. This double role for the Explorer program has repercussions with respect to mission sizes, foreign participation, and flight rate.

Finding 6. The panel believes that supporting a mix of Explorer mission sizes (MIDEX, SMEX, and UNEX) is an important and valuable feature of the program because it satisfies the needs of multiple constituencies. But this division should not be treated as immutable. Circumstances may change in the future and different cost caps may become preferable.

Finding 7. Based on the response to the 1995 MIDEX AO, the panel believes that the flight rate of Explorer missions could probably be substantially increased without any decrease in mission quality, if resources should become available.

Based on information contained in Explorer and Discovery solicitation documentation, the June 1996 MIDEX lessons-learned workshop report,[2] presentations by NASA and industry representatives, and its own findings, the panel offers the following recommendations:

Recommendation 1. The panel recommends that the two-step proposal process and other aspects of the next Explorer AO be discussed at a workshop before the AO is issued. In addition, debriefings for unsuccessful proposers should be expanded to include face-to-face discussions; the successful practice in the Discovery program might be used as a model.

Recommendation 2. The panel recommends that the Explorer and Discovery programs should continue with separate Headquarters management structures for the next few AOs.

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[2] "Medium class Explorers (MIDEX) Lessons-learned Workshop," NASA, 1996. Presented to the panel by the workshop chair, Kenneth Lang.

Recommendation 3. To reduce excess industry investment in detailed costing exercises for large numbers of missions during Step One, these proposals should be submitted on a "cost-not-to-exceed" basis within broad, AO-defined cost ranges. The responsibility for the cost-not-to-exceed estimate rests with the PI, advised by industrial and NASA center partners. The estimate should be accepted in Step One. A selected Step One effort that later failed to meet promised scientific objectives within the accepted cost limitation would be subject to termination and would be replaced.

Recommendation 4. NASA should clarify its approach to assessing new technology elements in future AOs. The panel notes that PIs and their partners can gain credit by combining new technology and an imaginative approach to managing the risk incurred.

Recommendation 5. The panel recommends that, at least for the next AO, foreign contributions be included in the Explorer cost cap as was done for the 1995 MIDEX AO. After more experience has been gained with foreign contributors and contributions, NASA and the science community should reassess this issue in workshops to be convened for the consideration of future AOs.

Recommendation 6. The panel recommends, in the same spirit as Recommendation 5, that NASA not add to the scope of the Explorer program until more experience has been gained with the next few AOs.

1

INTRODUCTION

The Early Explorers

Since the 1960s, the Explorer program at the Goddard Space Flight Center (GSFC) has been of crucial importance for the disciplines of space physics and space astronomy. Level funding for the Explorer program enabled these disciplines to develop many relatively small, Earth- and moon-orbiting missions that allowed these disciplines to progress, to develop new technologies and instruments, and to foster a substantial body of talented investigators. A capable scientific infrastructure developed that could support large ventures such as the Hubble Space Telescope and the other Great Observatories.

In the 1980s, Explorer began to depart from its small-and-frequent character and to put its resources into a few larger missions; for example, the X-ray Timing Explorer (XTE) and the Far-Ultraviolet Spectroscopic Explorer (FUSE) were both in the $200 million range.[1] A new program, the Small Explorer Mission (SMEX) line, was introduced to continue the classical small-mission capability, with a per-mission cost cap of $30 million. In the early 1990s, a line of very small satellites suitable for graduate student training, the Student Explorer Demonstration Initiative (STEDI), was independently introduced by the University Space Research Association. Costs of projects in the STEDI program were to be $5 million or less each.

During this period the Explorer and SMEX programs were for the most part perceived to be essentially "in-house" GSFC programs. NASA headquarters has always had an oversight role and final say in the selection of missions and investigators and, later on, in some aspects of the procurement of spacecraft. Nonetheless, although there have been experiments with alternative management arrangements (e.g., the Advanced Composition Explorer and the Active Magnetosphere Particle Tracer Explorer), GSFC has had management responsibility for most Explorer and SMEX missions. The Space Studies Board has offered a number of assessments and suggestions for the Explorer program during the past two decades.[2]

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[1]Explorer practice has been to include in the mission cost the expenditures for the development phase of the mission, the construction phase, operations up to 30 days after launch, and, until recent times, subsequent costs of mission operations and data analysis (MO&DA). Proposal costs and launch costs were not included in these cost figures.

[2]Space Studies Board, National Research Council, *A Strategy for Space Astronomy and Astrophysics for the 1980s*, Committee on Space Astronomy and Astrophysics, National Academy of Sciences, Washington, D.C., 1979.
Space Studies Board, National Research Council, *Solar-System Space Physics in the 1980s: A Research Strategy*, Committee on Solar and Space Physics, National Academy of Sciences, Washington, D.C., 1980.
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Changing Times

As the 1990s progressed, several external influences acted to force a reappraisal of NASA's general approach to space science missions. Efforts to reduce the federal budget deficit intensified budget pressures on discretionary activities like the space program, making it hard to start new programs. At the same time, defense technology developed during the Cold War began to emerge for civilian use. Many of these technologies were directly applicable to systems and instrumentation for space science.

Also during this period, the research community recognized the increasing duration of major mission life cycles, which were coming to extend over several decades in some cases. Undesirable consequences included freezing technologies, team compositions, and science objectives over long periods, which in turn precluded use of new technical capabilities, exploitation of new opportunities, or the introduction of new ideas. In addition, several highly visible failures, such as the malfigured Hubble Space Telescope mirror, the fouled Galileo high-gain antenna, and the total loss of Mars Observer, highlighted the vulnerability of a flight program consisting of a few very expensive, albeit very capable, missions. NASA's new Administrator, Daniel Goldin, pushed to restructure flight programs toward more frequent launches of smaller missions that would be solicited, selected, developed, and flown on much shorter time scales.

The budget pressures acting on flagship-class interplanetary missions and the Great Observatories have also forced fundamental changes in NASA's organizational philosophy. In response to these forces and to consequences of the National Performance Review,[3] the agency's Headquarters personnel complement has been dramatically reduced. Many management functions are being devolved to field centers. While some especially sensitive functions are being retained at Headquarters, NASA's program management is in a state of flux.

Discovery and the New Explorers

In response, NASA's space science programs have been changing rapidly. The Discovery program for planetary exploration has introduced new management concepts: mission costs were capped at a level far below those of recent planetary missions; the scientific community, industry, and field centers have been led to understand that cancellation would be the response to overruns; and missions were to be under the sole and complete control of a principal investigator (PI), who had previously had control only over science and instruments. The purpose of the latter requirement was to ensure that each mission would be planned and executed in a manner that would optimize the mission and its science output. The manner in which a PI carries out this responsibility is to be described in each project's initiating proposal, but is expected to involve partnerships with industry and with a field center, with a Memorandum of Understanding carefully defining roles and responsibilities developed early in the planning phase. In this report, the term "PI mode" is defined by these considerations.

Management of the Discovery program was maintained at Headquarters so as to be independent of competing field centers. Program managers made a major effort to discuss with all segments of the planetary community the manner in which Discovery proposals would be solicited (the Announcement of Opportunity, or AO). The result was a high level of enthusiasm amongst the science community and industry, with 73 mission concepts identified at a Discovery workshop in 1992, followed by 28 full proposals for what turned out to be two final selections.[4] After each stage in the selection process (which itself involved a very large effort), Discovery managers debriefed losing proposers face to face, a

[3] *Creating a Government That Works Better and Costs Less—Report of the National Performance Review*, U.S. Superintendent of Documents, Washington D.C., September 10, 1993.

[4] Two earlier, noncompetitive selections were also made for Discovery.

technique that paid off handsomely in terms of acceptance of the process and of the possibility of improved proposals for the next AO. A "lessons-learned" workshop with members of the planetary science community held after selection of winners identified many possibilities for improvement but no fundamental problems with the Discovery concept.

The Explorer program was restructured during the same period of time in a way that showed both similarities to and differences from Discovery (details are provided in Section 2). Explorer was reorganized into three classes. SMEX was retained, but with a cost cap of $35 million. The Mid-Size Explorer (MIDEX) was introduced with a cost cap of $70 million, and STEDI was taken over as the University Explorer (UNEX) program, with a cost cap of $5 million, all in 1994 dollars. The cap refers to the charge to the Explorer budget line. The intended flight frequency is one SMEX and one MIDEX per year, with two flights per year for UNEX. Most management functions, apart from final selection, were retained at GSFC.

The First MIDEX Competition

One MIDEX selection has been made to date under the new Explorer program. Forty-three proposals were submitted in a two-step process; after a Step One down-selection to 13 proposals, two primary and two alternate missions were selected in April 1996. Since the selection, there has been a pervasive sense in the proposing community that the process was flawed in several respects. For example, while it was possible to propose in a "PI mode," in which the PI assumes full responsibility for all aspects of mission definition, development, and execution, the AO also allowed proposing in a more traditional manner, the "NASA-provided spacecraft mode." In the more traditional approach, projects were to be conducted under GSFC management, with the PI responsible for science and instruments only. This choice of management models is referred to as the "dual mode option." While the two modes had different cost caps, the traditional mode appeared to the community to have two great advantages: government costs, including salaries of GSFC personnel, were not counted, and GSFC management was perceived to be strongly biased in its favor. Both of the primary winners (the Microwave Anisotropy Probe and the Imager for Magnetopause-to-Aurora Global Exploration) were proposed in the traditional mode of management. Industry and researchers alike believed that "PI mode" proposals stood little chance of selection.

In response to this discontent, a "lessons-learned" workshop was held at Hampton, Virginia, on June 26 and 27, 1996. The report of this workshop[5] was made available to the present panel. The lessons-learned workshop identified problems with the MIDEX process in four general areas: the two-step selection process, the "dual mode option," selection criteria applied, and proposal cost assessment. The present panel considered the results of the workshop during its deliberations; a brief survey of the key findings in the workshop report is as follows:

- *Two-step process.* Cost and risk were perceived to be unevenly and in some cases inexpertly analyzed in Step One, and too many proposals (13) were graduated to Step Two. Some proposers did not have an opportunity to clear up perceived misunderstandings by reviewers of key elements of their proposals. It was also noted that the oral debriefings to losing teams were inadequate (a point that was later emphasized in discussions with the current panel).
- *Dual mode option.* According to the report, differences in the information required for a "PI-mode" proposal, on the one hand, and for a "NASA-provided spacecraft mode" proposal, on the other, created confusion among the proposers. Cost versus risk assessments were also

[5] "Medium class Explorer (MIDEX): Lessons-learned Workshop," NASA, 1996. Presented to the panel by the workshop chair, Kenneth Lang.

applied differently for the two modes. Teaming with outside investigators was voluntary for GSFC participants, and the center's support capabilities were not made available to all on an equitable basis, especially for Step One. (An analogous problem later became evident to the present panel when industry representatives noted that it was impossible for companies to invest in more than a few of the many Step One proposals, thus requiring that they judge the relative scientific merit of projects seeking a corporate partnership.)

- *Selection criteria.* A key issue identified in the 1996 workshop report was the evaluation of proposed use of new technology: Was it viewed as a net benefit or drawback (due to perceived increase in risk)?
- *Cost assessment.* The 1996 workshop report stated that the relative costing of proposals with different levels of NASA participation was inequitable in the absence of full cost accounting of government contributions. Also, it stated that contractors' past cost performance should be taken into account during evaluation cost assessments.

Dissatisfaction with the MIDEX process may be contrasted with the present community support for the Discovery program, which is comparably highly competitive within the planetary exploration community.

2

COMPARING THE MIDEX AND DISCOVERY SOLICITATIONS AND SELECTIONS

The first Announcement of Opportunity (AO) for the MIDEX program had the objective of selecting two primary missions for flight development and two back-up missions. The AO was patterned on previous Explorer AOs, particularly on those of the SMEX program, with modifications reflecting appropriate features of the first Discovery AO and other agency requirements.

Recently, a second Discovery AO (Discovery 5) has been released, building on experience with the previous Discovery AO and with the 1995 MIDEX AO. Similarities and differences between these two AOs are given in tabular form in Appendix B. The extent to which the panel found one to be preferable to the other is brought out in the findings and recommendations in Section 3. Discussed here are some specific differences that are relevant to the MIDEX lessons-learned workshop.[1] That workshop presented its conclusions under four headings: the Two-Step Selection Process, Options for Spacecraft Procurement, Application of Selection Criteria, and Cost Assessment.

The Two-Step Selection Process

The purpose of the two-step process is to minimize the number of proposals for which detailed cost estimates must be developed.

In the 1995 MIDEX AO, Step One proposals gave details of the science investigation, including data analysis, a description of the technical approach, an outline of costs, and a management plan. NASA selected 13 out of 43 submitted proposals for Step Two evaluation. Step One evaluation employed the following criteria:

- Overall scientific and technical merit of the proposed mission, including a minimum science mission, and its contribution to space science;
- Total cost and adequacy of the approach to perform the mission for that cost; and
- Adequacy and completeness of the data reduction and analysis plan, including arrangements for the timely release of data to the public domain.

The first two criteria were primary and of equal importance, while the third was less important. Because of the limited cost information in Step One, evaluations assumed that the cost was a "cost-not-to-exceed." NASA could terminate the mission if costs rose above this figure.

Step Two proposals for the 1995 MIDEX AO included detailed technical, cost, and management plans. Three months were allowed between Step One selection and submission of the Step Two proposal; no NASA funding was provided to support Step Two proposal development (unlike the Discovery 5 solicitation). Step Two proposals were evaluated against the following criteria:

[1] "Medium-class Explorers (MIDEX) Lessons-learned Workshop," NASA, 1996. Presented to the panel by the workshop chair, Kenneth Lang.

- Scientific and technical merit, including the minimum science mission and its likely contribution to space science;
- Total cost, and realism of that cost;
- Adequacy of the proposed approach to fulfill the mission objectives within the stated cost caps;
- Overall merit of the management plan, including the experience, level of commitment, and prior performance of the investigator's institution, as well as the capabilities of the key personnel and their prior experience in NASA programs; and
- Adequacy and completeness of the data reduction and analysis plan, including arrangements for the timely release of data to the public domain.

The first three criteria were primary and of equal importance, while the next two were equal and of less importance. A sixth criterion was listed for consideration during evaluation, though with lower weight than the other five:

- The proposed approach to implementing advanced technologies, subcontracting goals for small and disadvantaged business, and educational and public outreach programs.

In the Discovery 5 AO, Step One will be the primary selection for a small number of proposals (four to six) that will be funded for Step Two feasibility studies. The evaluation criteria for Step One proposals are the following:

- Scientific merit;
- Total mission cost to NASA;
- Technical merit and feasibility of the science investigation;
- Feasibility of the mission implementation scheme; and
- Education, outreach, new technology, and small and disadvantaged business activities.

The first criterion will have the greatest weight, followed by the second. The remaining three will be given lower, and approximately equal, weight. During Step One the cost is required only to be within 20% of its eventual value.

The few proposals selected from Step One will be funded for five-month feasibility studies up to $350,000 each. Evaluation criteria for Step Two will be the same as for Step One, but will stress details of implementation, and with an additional criterion, "value for cost to NASA." This criterion is defined by an algorithm combining figures of merit for science (80%) with education, outreach, new technology and small and disadvantaged business activities (20%), divided by the NASA portion of the total mission cost. The relative weight for this criterion is not specified. After Step Two evaluation, one or more missions will be selected for Phase A/B (advanced study and definition phase) studies.

Options for Spacecraft Procurement

The 1995 MIDEX AO offered proposers two options for the spacecraft portion of the mission. In the first the principal investigator (PI) would propose an investigation and an instrument to fly on a spacecraft developed or procured by GSFC; project management would reside at GSFC. Called the "NASA-provided spacecraft mode," this has been the traditional mode for the Explorer program. In the second option (the "PI mode"), the PI would take full responsibility for all aspects of the mission, from definition of the instrument and the spacecraft to mission operations and data analysis. In the "PI mode," a proposer could designate a NASA center for project and mission management, but the overall

responsibility would remain with the PI. In either case, the Goddard Space Flight Center (GSFC) had responsibility for oversight to ensure efficient use of federal funds.

The Discovery 5 AO allows only the "PI mode"; essential NASA oversight will be provided by an appropriate center.

Application of Selection Criteria

The MIDEX lessons-learned workshop expressed concern about the application of selection criteria in both Step One and Step Two for the 1995 MIDEX AO. Science, technical, and cost criteria were judged at the same time in both steps; only the emphases differed. Concerns were expressed in the workshop about the ability of any evaluation group to command all the skills needed to cover the wide range of subdisciplines spanned by the Explorer program. There was also concern about the difficulty that proposers faced in making complex arguments adequately within the limited format of the proposal. The workshop's suggested solution to these problems is that proposers and evaluators interact during the evaluation process. The present panel was not apprised of any plans for an interactive process in future Explorer or Discovery AOs.

Cost Assessment

Cost Evaluation Criteria

NASA is moving toward considering the full cost of missions in budget development (full cost accounting). This will include not only the budget line item for a given project (usually design, development and 30 days of operations), but also Mission Operations and Data Analysis (MO&DA) costs, launch vehicle costs, civil service salaries, and appropriate support costs. MIDEX, on the contrary, was based only on the line item costs. MO&DA costs were considered separately against their own cap; all other costs were excluded.

Discovery 5 cost caps apply to total cost to NASA, including civil service salaries, launch vehicle costs, and support costs up to launch plus 30 days. Subsequent MO&DA costs are limited by an additional, separate cap. This represents a major step toward full cost accounting.

International Cooperation

International cooperation was welcomed in the 1995 MIDEX AO, provided that the proposed cooperative mission fitted within the MIDEX cost caps. International cooperation would be conducted on a no-exchange-of-funds basis and in close coordination with the appropriate U.S. scientific community.

The Discovery program's provision for international participation is similar, but the foreign contribution is not counted against the cost cap; instead, it has a cost cap of its own equal to one-third of the U.S. Phase C/D (detailed design and development phase) expenditure. Launch vehicles and services provided by international partners are not included in this cap.

Partnership with Other U.S. Institutions

The 1995 MIDEX AO allowed the possibility of partnerships with other U.S. agencies or institutions. The same conditions applied as for foreign contributions.

The Discovery 5 AO also permits contributions from U.S. agencies and institutions outside NASA's Office of Space Science, and it applies the same conditions as apply to international participation.

Project Cost Caps

Explorer missions are divided into three categories, UNEX, SMEX, and MIDEX, with three different cost caps: $5 million, $35 million, and $70 million (FY 1994 dollars), respectively. This implies cost ranges for individual Explorer AOs, e.g., $35 million to $70 million for a MIDEX AO, providing for some grouping of missions with respect to size, complexity, and cost.

No ranges exist in the Discovery 5 AO: proposals may be made at any level up to the cost cap, $183 million (FY 1997 dollars). MO&DA costs after 30 days postlaunch are capped at $43 million, computed according to the same principles as the development budget.

3

ISSUES, FINDINGS, AND RECOMMENDATIONS

Research Community Engagement

The policies that led to establishment of the Discovery program and to reformulation of the Explorer program have profound implications for NASA management, for NASA centers, for industry, and for the science community. These policies are summarized in the panel's charge: "missions in these level-of-effort programs should be defined and developed by the Space Science community itself instead of by the Agency. . . . the Principal Investigator (PI) proposes both the payload to complete a science investigation as well as the spacecraft as an integrated package . . ." Although variants of the "PI mode" have been used in earlier missions, including some Explorer missions, this is the first time that its use has become general agency policy.

In the course of panel discussions, representatives of each component of the space science community (NASA Headquarters and field centers, industry, and scientists) expressed uncertainties about the "PI mode" of management, which places accountability for scientific integrity, as well as final authority and responsibility for execution of a mission, on the PI. The PI is responsible for assembling the organization that will conduct the mission, ensuring implementation of the mission on schedule and within cost, and making trade-off decisions to achieve the best possible scientific results. Project management and all related management issues are to be identified and fully addressed by the PI in the initiating proposal.

General introduction of the "PI mode" represents a major change in NASA project management, and it has consequences, not all of which are understood. One panel member raised the question: How is it established that a PI has the necessary experience to carry out a space mission? Another commented that the demanding requirements for PI management skills could eliminate from competition excellent scientists with important new ideas, but lacking management experience. A third speculated that it will eliminate smaller efforts by isolated individuals who may not be sufficiently well connected to become part of the larger effort necessary to conduct a full-up spacecraft venture. These problems can only be resolved on the basis of experience with the "PI mode," and NASA needs to keep the matter under continual review by means of preproposal workshops and lessons-learned workshops. The goal must be, as it has been in the past, to optimize the space program's advancement of human knowledge within the limitations imposed on the program. Despite the questions raised, the panel concluded that use of the "PI mode" can be an important step toward this goal.

Historically, NASA's science program has been led by management and engineering teams at the Jet Propulsion Laboratory or NASA centers. Community input to mission planning was usually through internal and National Research Council planning committees. For the smaller missions of the new Explorer program, leadership roles are fundamentally changed in the "PI mode." The panel believes that many of the difficulties encountered in the first (1995) MIDEX selection arose from conservative instincts associated with a 25-year history of past successes attained with a different management model.

These difficulties should diminish as all parties accustom themselves to the "PI mode" for these smaller missions.[1]

Finding 1. The panel supports use of the "PI mode" by NASA. It brings new vigor to the program at a time when diminishing opportunities could lead to disillusionment amongst the science community. It is an open process that appears to be intrinsically fair. It has exposed a reservoir of ideas for focused science under a cost cap.

A strong program requires good communications between NASA and the science community. This includes communication from NASA to the science community about the goals and structure of the program, and from the community to NASA about the ways in which the program can be implemented. This process should begin sufficiently in advance of an AO to allow modifications to that AO. The program depends for its success on the enthusiastic support of a diverse community, and a deliberate effort is required to engage its members. Comparison between the Explorer and the Discovery programs shows that the effort made by the Discovery program paid off, while that for the 1995 MIDEX AO was insufficient. Some of the features of Headquarters' planning for the next Explorer AO were presented to the present panel. While this planning appeared to respond positively to many of the suggestions of the 1996 MIDEX lessons-learned workshop, there were aspects that might not command broad support from potential investigators. A broader discussion of these plans in a community workshop involving the relevant scientific community is needed to ensure an effective and equitable process in the new "PI mode."

Communications that followed the 1995 MIDEX selections were also unsatisfactory. Face-to-face debriefings with science and industry participants are essential for two reasons. First, the proposers must be given a full accounting so that they can accept the essential fairness of the process. Second, investigators can learn how to improve their proposals, which can lead to a better program. Again, the panel was impressed with the effort made by the Discovery program in this respect and concluded that the Explorer effort was insufficient.

Finding 2. The panel believes that the new Explorer program cannot succeed without a high level of support by the science community. In the first (1995) MIDEX solicitation the most readily avoidable errors were failure to consult adequately with the community in the development of the AO and failure to undertake face-to-face debriefings with investigators after the process. These management errors have led to problems with the science community, but they can be resolved through a thoughtful effort in developing future AOs, and again after selection has taken place.

Recommendation 1. The panel recommends that the two-step proposal process and other aspects of the next Explorer AO be discussed at a workshop before the AO is issued. In addition, debriefings for unsuccessful proposers should be expanded to include face-to-face discussions; the successful practice in the Discovery program might be used as a model.

Field Centers and Program Management

In the past, the Goddard Space Flight Center (GSFC) has been principally responsible for managing Explorer missions. The center has also played a part in program management, traditionally a

[1]As the role of NASA centers evolves, there is a concern about maintaining the expertise of government scientists and engineers. The Space Studies Board addressed these issues directly in a recent letter report. See *Space Studies Board Annual Report—1995*, pp. 74-77, National Academy Press, Washington, D.C.

Headquarters' prerogative. With the continuing contraction of Headquarters staff, the transfer of functions from Headquarters to GSFC continues, although final selection decisions are expected to remain at Headquarters.

There has always been a perception amongst outside scientists and industry that GSFC "owned" the Explorer program. Transfer of additional functions from Headquarters does nothing to decrease this impression. At first sight this situation is not compatible with the responsibilities of the PI under the "PI mode," an impression that was confirmed by the first MIDEX AO's "dual mode option." In the 1996 MIDEX lessons-learned workshop the "dual mode option" was identified as a feature that must be eliminated if selection is to be seen to be fair.

Finding 3. The panel understands from presentations made to it that the "dual mode option" will be eliminated from future Explorer AOs and that the "PI mode" will be the *only* management approach allowed. The panel endorses this decision.

The second issue that most concerned the lessons-learned workshop was the absence of full cost accounting for civil service time and facilities. This was seen to be a further instance of favoring GSFC projects and the GSFC mode of management.

Full cost accounting presents many technical difficulties. NASA is committed to this course, but it will take time before a satisfactory method is in place. Given both adoption of the "PI mode" and full cost accounting, the precise management arrangements between GSFC and Headquarters may become less critical. However, efforts to explain these changes should continue. An appearance of even-handedness between NASA centers on the one hand, and industry and the science community on the other hand, is essential for a successful Explorer program. NASA has always understood that it draws great strength from the support of institutions outside the agency, and it has worked hard to maintain and improve its good relationships. The Explorer and Discovery programs place additional demands on these relationships which must be matched by additional efforts by NASA management. Recent changes in upper-level management at GSFC and in the management of the Explorer program encourage the panel to believe that this message has been heard and is being acted upon.

Finding 4. The panel concludes that the new Explorer program at GSFC is well managed and is aggressively moving to fully support the "PI mode" management approach. This includes a move to full cost accounting for government contributions.

Once an AO has been issued it is essential that its provisions be followed rigorously. The panel understands that "shifting the goal posts" may occur for reasons not under the control of program management, but the results of doing so can be damaging and long-lived. If substantial changes are required to a future Explorer AO after it is released, it may be better for the relationships between NASA and the community to withdraw it and issue a new AO.

Part of the long-term vision for space science at NASA is to merge the Discovery and Explorer programs so that the combined program can serve the entire community. A step in this direction has already been taken by appointing a single manager for both programs at Headquarters. The panel appreciates the arguments in favor of this long-term objective but has reservations about the wisdom of moving too rapidly in this direction. The 1995 MIDEX selection had difficulties with fairness with respect to physics and astronomy subdisciplines (the AO lists seven space physics and eight space astronomy subdisciplines). Until the research community is satisfied with the means by which selection is made among subdisciplines, it seems unwise to add to the diversity by including planetary interests. As an example of the problems involved, consider a possible comparison between the planetary community's emphasis on exploration and the search for detailed mechanisms that dominates space

physics. The Explorer and Discovery programs are both changing and adjusting, and they should be given time to settle down before additional management challenges are introduced.

Recommendation 2. The panel recommends that the Explorer and Discovery programs should continue with separate Headquarters management structures for the next few AOs.

Industry

Historically, industry has played a major role in the development of both instruments and spacecraft through competitive selection after mission definition. The change to a "PI mode" of management and the low-cost concepts of Explorer and Discovery are new circumstances that industry must adapt to.

A PI needs early information about costs that can ordinarily come only from industry. The way in which this information is brought together is a matter for the PI to decide, but a common approach will be to establish a partnership between the PI, an industrial partner, and a NASA center, with the modus operandi carefully defined in a Memorandum of Understanding. Without such a partnership, or something equivalent to it, it may be very difficult to prepare competitive proposals in which price and capability are key elements. The panel was therefore concerned to learn that government procurement constraints may interfere with government PIs who wish to form early partnerships with industry. If this issue is not dealt with soon it will impose serious problems in future Explorer AOs.

A concern frequently raised by industry representatives is that they wish to understand the ground rules of competition, specifically whether GSFC is a customer or a competitor. The relationship should be clear in each individual case. For example, the panel believes that a problem was created by the "dual-mode option" of the 1995 MIDEX AO. If, as the panel was given to understand, future AOs will permit only the "PI mode," this issue should not arise. GSFC can be the spacecraft provider if the PI so wishes, and GSFC may ask industry to compete for that opportunity, in which case GSFC is the customer. Alternately, the PI may go directly to industry, and the team that is put together may compete against a GSFC team. While these arrangements are not the traditional way of doing business, the panel sees no grounds for confusion if the critical role of the PI is recognized and the teaming approach is clearly laid out in each proposal.

Another concern for industry is the high cost of developing a reliable detailed mission cost estimate for a proposal. In practice, this means that most firms will not be willing to expend the resources necessary to propose a cost, or a not-to-exceed figure, unless the competition is reduced to four or fewer competitors. Experience shows that there are about forty groups willing to make Explorer proposals, a healthy feature of the process that needs to be preserved. The discrepancy between four finalists and forty proposers has led the Explorer program (and also the Discovery and Earth Systems Science Pathfinder programs) to a two-step AO, in which the first step is used to winnow the field by a process involving no detailed costing. The panel heard three or four variants of the two-step process, all of which have shortcomings. The fundamental dilemma is that if adequate cost estimates are not available for evaluation in Step One, how is it possible to ensure that the best proposals are not eliminated before their high science-per-dollar value can be demonstrated in Step Two?

The best solution has yet to be found, but the Explorer program has helped itself by carrying two cost classes, MIDEX and SMEX. With this division the PI can choose from two broad cost ranges, which define the science-per-dollar better than a single universal cap. Industrial estimates or ROMs ("rough-order-of-magnitude" estimates), together with past experience, can be used to decide which cost class is appropriate.

The panel believes that it is consistent with the spirit of the "PI mode" of proposal that a PI's estimate of a cost-not-to-exceed be accepted for Step One. If this cost is exceeded in Step Two or at a

later date, the effort should be terminated. A capable PI, supported by an experienced industrial partner and advised by experienced managers in a NASA center, should be able to succeed. The panel regards as unwarranted a concern that all PIs selected in a given competition might fail.

Recommendation 3. To reduce excess industry investment in detailed costing exercises for large numbers of missions during Step One, these proposals should be submitted on a "cost-not-to-exceed" basis within broad, AO-defined cost ranges. The responsibility for the cost-not-to-exceed estimate rests with the PI, advised by industrial and NASA center partners. The estimate should be accepted in Step One. A selected Step One effort that later failed to meet promised scientific objectives within the accepted cost limitation would be subject to termination and would be replaced.

Finally, industry has expressed concern about the trade-offs between new technology and risk. The effect of including new technology in the first round of MIDEX Step One proposals has not been clearly understood. As a result, there is an apparent contradiction between NASA's wish to advance new technologies and the old adage that you may take risks provided you do not fail.

Recommendation 4. NASA should clarify its approach to assessing new technology elements in future AOs. The panel notes that PIs and their partners can gain credit by combining new technology and an imaginative approach to managing the risk incurred.

Science Effectiveness

The panel considered the science effectiveness of Explorer missions only in the context of the limited scope imposed on these missions by NASA. No attempt was made to assess the relative science value and effectiveness of Explorer versus larger missions.

Finding 5. The panel believes that the restructured Explorer program can be of outstanding value not only for the science performed, but also for its role in maintaining U.S. scientific capabilities in an important area of space science. This double role for the Explorer program has repercussions with respect to mission sizes, foreign participation, and flight rate.

Different elements of the science community require different mission capabilities. A mature science concept may require the full capabilities of a MIDEX-class mission and more, while innovative ideas and new instrumentation may be more appropriate to SMEX. UNEX caters to graduate students and the next generation of investigators.

Finding 6. The panel believes that supporting a mix of Explorer mission sizes (MIDEX, SMEX, and UNEX) is an important and valuable feature of the program because it satisfies the needs of multiple constituencies. But this division should not be treated as immutable. Circumstances may change in the future and different cost caps may become preferable.

Foreign participation in Explorer is a debatable issue because science value and the preservation of U.S. capabilities may come into conflict. For individual scientists, the possibility of leveraging Explorer contributions with foreign resources is very attractive, and this option may be taken up frequently if it is seen to be advantageous. Such proposals will probably rank high in evaluations based up science per (U.S.) dollar. Unfortunately, such missions do not have the same value for preserving U.S. capabilities as do U.S. missions. In addition, substantial foreign participation gives rise to management issues that have not yet been fully addressed: loss of control over cost containment, with

subsequent costs to the U.S. component of the mission; additional costs to the U.S. MO&DA budget due to nonstandard data management procedures and software; and uncertain definition of the scope of the science review when different entities and procedures are involved. For these reasons the panel was concerned to be told that a cost cap on foreign contributions that was placed on the 1995 MIDEX AO will be removed, and that foreign contributions will not be limited in future AOs.

Recommendation 5. The panel recommends that, at least for the next AO, foreign contributions be included in the Explorer cost cap as was done for the 1995 MIDEX AO. After more experience has been gained with foreign contributors and contributions, NASA and the science community should reassess this issue in workshops to be convened for the consideration of future AOs.

The panel was also informed that U.S. contributions to foreign missions, as well as to suborbital missions using balloons, rockets, and aircraft, may also be merged with the Explorer program. In the past, these activities have been managed and funded independently. The panel was concerned that the overall effectiveness of NASA's physics and astronomy programs might be affected unfavorably by the addition of obligations to the Explorer program at a time when so many other changes are occurring.

Recommendation 6. The panel recommends, in the same spirit as Recommendation 5, that NASA not add to the scope of the Explorer program until more experience has been gained with the next few AOs.

One of the major factors affecting the vigor of the science program and its investigators is an adequate flight rate, with minimum time spent in the preparatory phases of a mission. The time between release of an AO and launch should be kept to a minimum to enable ideas to be translated into scientific results as soon as possible. What is an appropriate launch rate? There were approximately forty proposals under the 1995 MIDEX AO. This appears to be an appropriate size for the investigator pool for space astronomy and space physics and their subdisciplines. The panel could not speculate on the incidence of "excellent" proposals or on the rate of turnover of new ideas, but the launch rate of one SMEX and one MIDEX per year (UNEX is a separate case) appears to be small compared to the capabilities of this community.

Finding 7. Based on the response to the 1995 MIDEX AO, the panel believes that the flight rate of Explorer missions could probably be substantially increased without any decrease in mission quality, if resources should become available.

Conclusion

General Finding. The panel believes that most of the perceived problems brought to light after the first (1995) MIDEX AO were due to the "dual mode option" and the lack of full cost accounting for government contributions. In addition, debriefing of unsuccessful proposal teams was not adequate. While the AO and the selection process both need improvement, and while interaction with the science community also needs to be strengthened, the panel believes that the program is now on the right path and that the new Explorer program should be excellent if properly administered. The perception will probably continue that GSFC and its scientists have an advantage, but the panel is satisfied that the Explorer program management is addressing this issue and that elimination of the recognized flaws will bring about a level playing field for both scientists and industry. Given time and continuing effort, it is the belief of the panel that the astronomy and space physics communities will strongly support the program.

APPENDIX A

MEETING PARTICIPANTS
SEPTEMBER 12-14, 1996

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APPENDIX B

COMPARISON OF PROPOSAL ELEMENTS: 1995 MIDEX AND DISCOVERY 5

PROGRAM TOPICS

AO Topic	1995 MIDEX	Discovery 5
AO Process	Two-step process: Step One serves as "filter" to screen best proposals; Step Two selects two missions for study and definition and two as alternates	Two step process: Step One selects four to six missions for feasibility study; Step Two (funded feasibility study) selects one or more missions for definition and development
Minimum Science Mission	Evaluated along with baseline mission	Evaluated along with baseline mission
Procurement Mode	Dual mode, either traditional Explorer (PI instrument on NASA spacecraft) or PI mode (entire mission managed by PI)	PI mode only
NASA Oversight	Goddard Space Flight Center, whether traditional Explorer or PI mode	Appropriate NASA center
Cost Constraints (Caps)	• Definition through development plus 30-days of operation (Phases B through D) less than or equal to $70 million (in FY 1994 dollars); outside contributions to be included • Allocation for instruments less than or equal to $40 million and spacecraft less than or equal to $30 million • MO&DA less than or equal to $5 million per year to total less than or equal to $15 million	• Advanced study and definition (Phases A/B) less than or equal to 10% of design and development (Phases C/D) • Phases C/D less than or equal to $183 million (in FY 1997 dollars); outside contributions to be excluded • MO&DA less than or equal to $43 million
Cost Growth	None permitted (except as covered within 15% required reserve)	Not to exceed 20% of cost proposed in Step One; not to exceed cap
Cost Evaluation Criteria	Cost proposals considered against caps (above). Note that applied caps excluded launch vehicle and civil service staff, but included contributions	Evaluation to be based on total mission cost to NASA (including launch vehicle, civil service staff); excludes contributions
International Cooperation	Welcomed, provided overall mission consistent in scope with other MIDEX missions (i.e., contributions counted against cap)	• Welcomed; cost contribution limited to 1/3 of U.S. contribution to design and development (or $61 million, whichever larger) but excluded from cap • Launch services not so limited
Partnerships with Other U.S. Institutions	Same as for international partnerships	Same as for international partnerships

STEP-ONE TOPICS

AO Topic	MIDEX	Discovery 5
Step-One Purpose	Screening of proposals to identify the best ones for detailed evaluation (Step Two)	Full evaluation of proposals to determine best for feasibility study funding
Step-One Evaluation	• Evaluated primarily on scientific and technical merit and "not-to-exceed"cost • Data and analysis plan considered, as well • Evaluation by scientific/technical peers	• Evaluated primarily on scientific merit and total NASA cost • Technical merit and feasibility, mission implementation plan, other factors considered • Evaluation by scientific/technical peers
Step-One Results	13 of 43 proposals selected for Step-Two evaluation	Four to six proposals to be selected for Step-Two funded feasibility studies

STEP-TWO TOPICS

AO Topic	MIDEX	Discovery 5
Step-Two Purpose	Selection of missions for funded advanced study, definition, and development	Selection of missions for further definition and development
Step-Two Contractual Arrangement and Funding	None	Feasibility study contracts (funded up to $350,000 each, in FY 1997 dollars) with options for all subsequent mission phases
Step-Two Evaluation	• Scientific and technical merit (as changed) • Total cost and its realism • Proposed approach vis-à-vis mission objectives and cost • Management plan • Data reduction and analysis plan • Advanced technology, subcontracting goals, and outreach The first three have primary and equal priority; the next two are secondary and equal; the last is lower priority.	Same as for Step One, except: • Emphasis placed on implementing details • "Value for cost to NASA" added as criterion; parameter determined by an algorithm involving numerical values assigned for objectives met (e.g., science, technology) divided by NASA mission cost
Step-Two Results	Two missions selected for definition and development; two others selected as alternates	One or more to be selected for exercising of options for definition and development