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Foreword

Photographs of Earth from space show no political boundaries, reminding us that national distinctions are manmade. But the agencies responsible for those pictures, other missions to Earth orbit, and probes to deep space are inevitably national or multinational. Each has its own set of constituencies, procedures, capabilities, and limitations.

There are great benefits from finding ways those entities and their respective research and industrial communities can act cooperatively, as has been amply demonstrated by many successful examples of international cooperation in the space sciences. Beyond the cultural enrichment that comes when people of different nations work together for a common goal, those benefits include the potentially richer scientific yield from shared expertise and broader political and financial support.

Joint activities between the National Aeronautics and Space Administration in the United States and the European Space Agency or individual European national space agencies have resulted in some of the world's most successful space science missions, and more joint efforts are being planned. But inevitably, some attempts at transatlantic cooperation are more successful than others. Sometimes difficulties arise as they would in any large, complex technical undertaking, whether national or multinational. At other times, however, the additional complications of internationalism itself can cause or exacerbate those difficulties.

We believe that improving the likelihood of successful U.S.-European cooperation is a worthy goal that can enhance the space programs and benefit the peoples of all participating nations. This benefit is clearest in the case of the International Space Station, the largest multinational undertaking of its kind. Its success depends entirely on the cooperation of the United States, Europe, and the other major partners. We think improving international cooperation can also enhance more modest space missions that study Earth, explore the solar system, or probe the cosmos.

This joint report is itself an exercise in international cooperation. The Space Studies Board of the U.S. National Research Council and the European Space Science Committee of the European Science Foundation are charged with advising their respective space enterprises. Our charters, procedures, and operating styles are not identical. Yet we have a long history of fruitful interchange and a shared vision of science as a global activity, and this understanding provided a natural context for this study.

It is our hope that this report will help make future cooperative ventures in space science more successful than ever. Some of the conclusions may be relevant for those planning international ventures in other areas as well. We plan to continue our joint dialogue and hope to extend our deliberations to include colleagues in other major space-faring nations. We are confident that the spirit of shared human inquiry that has characterized science throughout history will continue and grow stronger on the high frontier of space research.

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Acknowledgment of Reviewers

This report has been reviewed by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council (NRC) Report Review Committee and agreed to by the European Science Foundation. The purpose of this independent review is to provide candid and critical comments that will assist the authors, NRC, and ESF in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The contents of the review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their participation in the review of this report:

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Although the individuals listed above have provided many constructive comments and suggestions, responsibility for the final content of this report rests solely with the authoring joint committee, NRC, and ESF.

This report could not have been written without the contributions of many colleagues who provided the joint committee with essential unpublished information. The members of the joint committee are very grateful to them.

*This reviewer, currently working at the European Space Agency, was not affiliated with the agency at the time of the review.

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U.S.-EUROPEAN COLLABORATION IN SPACE SCIENCE

Executive Summary

The United States and Europe have been cooperating in space science for more than three decades. This history of cooperation has survived significant geopolitical, economic, and technological changes, such as the end of the Cold War, the pressure of budget reductions, and the increasing focus on economic competition and the global marketplace. Both Europe and the United States have learned from one another and acquired a knowledge base as well as an infrastructure to implement joint missions and research activities. More importantly, the decades of cooperative space research efforts between the United States and Europe have built a community of scientists whose joint scientific exchanges have established a heritage of cooperation on both sides of the Atlantic.

The scientific fruits of this heritage are plainly evident in achievements such as a signature for supermassive black holes provided by the Hubble Space Telescope (HST); the first views of the solar atmosphere and corona illuminated by the Solar and Heliospheric Observatory (SOHO); the sharing of expensive research facilities on the International Microgravity Laboratory (IML); and the impressive data on ocean altimetry from the Ocean Topography Experiment (TOPEX-POSEIDON) mission, which is significantly improving our understanding of global ocean circulation.

There were no guideposts for the emergence of space science cooperation between Europe and the United States. In the process of introducing new procedures and improvements to facilitate cooperation, missteps occurred, and there were political, economic, and scientific losses. This report takes stock of U.S.-European history in cooperative space endeavors, the lessons it has demonstrated, and the opportunities it suggests to enhance and improve future U.S.-European cooperative efforts in the sciences conducted in space.

THE JOINT COMMITTEE'S TASK

The Committee on International Space Programs (CISP) of the Space Studies Board (SSB) and the European Space Science Committee (ESSC) were charged by the National Research Council (NRC) and the European Science Foundation (ESF), respectively, with conducting a joint study of U.S.-European collaboration in space missions. The study was initiated jointly by the SSB and the ESSC after discussions over several years on the increasing importance of international activities and the need to assess previous experience. This study was conducted by a joint SSB-ESSC committee.

The joint committee's central task was to analyze a set of U.S.-European cooperative missions in the space sciences, Earth sciences from space, and life and microgravity sciences and to determine what lessons could be learned regarding international agreements, mission planning, schedules, costs, and scientific contribution. Although the charge is largely retrospective and relies on existing or past missions, the joint committee found that in some cases, missions in the development stage offered the best (or only) examples that met the study criteria. The joint committee also determined that though a retrospective study was requested, lessons learned from the analyses must be considered within a prospective context to be relevant to future cooperative activities.

APPROACH

The joint committee agreed on a set of selected missions in the space science disciplines to be used as case studies in this report (Table ES.1). Both National Aeronautics and Space Administration–European Space Agency (NASA-ESA) endeavors and missions conducted between NASA and national space agencies in Europe have been included. In addition, the selection includes both smaller-scale missions managed by principal investigators (PIs) and larger missions managed at the agency level.

Each mission was briefly characterized, with special emphasis on the particular problems and benefits posed by its international makeup. The joint committee analyzed the history leading up to the mission, the nature of the cooperation, and the benefits or failures that accrued from conducting the cooperation. The following questions helped guide the joint committee's survey of the missions:

1. What were the scope and nature of the agreement? How did the agreement evolve, and how was it finalized? How long did it take to plan the mission?
2. How was the cooperation initiated (e.g., by scientist-to-scientist or agency-to-agency contact)? What was the role of each partner and agency? Were the motivations the same for all partners?
3. What were the expected benefits each partner offered?
4. What were the extent and practical mechanisms of cooperation? At what level, if any, did hardware integration of multinational components take place? How were communications maintained? Was the project structured to minimize friction between international partners?
5. What was the net impact of internationalization on the mission in terms of costs, schedule, and science output?
6. What external influences affected the mission during its life cycle? What were their effects? Were problems caused by different internal priorities or by external (e.g., political, financial) boundary conditions (such as budget cycles)?

TABLE ES.1 Missions Used as Case Studies in This Report, Selected by Discipline

Disciplines	NASA-ESA Case Studies	NASA-European National Space Agencies Case Studies
Astrophysics	HST, SOHO,[a] INTEGRAL	ROSAT
Planetary sciences	Cassini-Huygens, GMM	
Space physics	ISPM [Ulysses], ISEE	AMPTE
Earth sciences	EOS–Polar platforms	UARS, TOPEX-POSEIDON
Microgravity research and life sciences	IML-1, 2	IML-1, 2

NOTE: AMPTE = Active Magnetospheric Particle Tracer Explorer; EOS = Earth Observing System; GMM = Generic Mars Mission; HST = Hubble Space Telescope; IML = International Microgravity Laboratory; INTEGRAL = International Gamma-Ray Astrophysics Laboratory; ISEE = International Sun-Earth Explorer; ISPM = International Solar Polar Mission [renamed Ulysses]; ROSAT = Roentgen Satellite; TOPEX = (Ocean) Topography Experiment; UARS = Upper Atmosphere Research Satellite.

[a] The Solar and Heliospheric Observatory (SOHO) is used by both astrophysicists and space physicists. Its mission addresses both disciplines. For the purposes of this study, SOHO was analyzed as an astrophysics mission.

7. Were there issues of competition versus cooperation? Did the desire to protect technological leadership create problems?
8. What benefits did the cooperation actually produce?
9. Which agreements succeeded and which did not, in both scientific and programmatic terms?

The questions are not formally asked and answered for each mission case study but serve instead as guideposts. In the end, the joint committee sought to know and present the lessons learned and how they can be applied in the future.

RECOMMENDATIONS

The joint committee, having surveyed and analyzed the 13 U.S.-European cases discussed in Chapter 3, identified several conditions that either facilitated or hampered bilateral or multilateral cooperation in space science. Some of these conditions are unique to their scientific disciplines and their "cultures," whereas others are cross-cutting and apply overall to the cooperative experience between the United States and Europe, as analyzed in Chapters 2 and 3. The joint committee determined that these overarching factors can be organized according to the various phases of a cooperative program, namely (1) goals and rationale for international cooperation, (2) planning and identification of cooperative opportunities, (3) management and implementation, (4) personnel, and (5) guidelines and procedures. These factors led to five sets of recommendations.

Goals and Rationale for International Cooperation

The joint committee's examination of U.S.-European missions over more than 30 years shows, in retrospect, that international cooperation has at times been used to justify a mission that may have lacked support from the scientific community at large or other factors important for successful cooperation. (This was particularly true for the International Gamma-Ray Astrophysics Laboratory [INTEGRAL] mission, which lacked broad support within the U.S. astronomical community.)

Finding: Based on its analysis of 13 case missions involving U.S.-European cooperation, the joint committee identified eight key elements that it believes are essential to success in international cooperation in space missions.

1. *Scientific support.* The international character of a mission is no guarantee of its realization. The best and most accepted method to establish compelling scientific justification of a mission and its components is peer review by international experts. Expert reviewers can verify that the science is of excellent quality and meets high international standards, the methods proposed are appropriate and cost effective, the results meet a clear scientific need, there are clear beneficiaries in partners' countries, and the international program has clear requirements.

From a budgetary and political point of view, the mission must have strong support from the scientific community in a timely manner to overcome budget restrictions (and political hurdles). All partners and funding agencies need to recognize that international cooperative efforts should not be entered into solely because they are international in scope.

2. *Historical foundation.* The success of any international cooperative endeavor is more likely if the partners have a common scientific heritage—that is, a history and basis of cooperation and a context within which a scientific mission fits. This context encompasses a common understanding of the science that can lead to the establishment of common goals. A common heritage also allows the scientific rationale to be tested against other priorities.

3. *Shared objectives.* Shared goals and objectives for international cooperation must go beyond scientists to include the engineers and others involved in a joint mission. One of the most important lessons learned from the years of space research is that "intellectual distance" between the engineering and scientific communities and the accompanying lack of common goals and objectives can have a detrimental effect on missions. The penalty is that the mission project is, at best, only partially successful and, at worst, a total failure. Close interaction is particularly important at the design phase—for example, the participation of scientists in monthly engineering meetings

can help to support optimal planning when compromises are needed between scientific goals and technical feasibility.

4. *Clearly defined responsibilities.* Cooperative programs must involve a clear understanding of how the responsibilities of the mission are to be shared among the partners, a clear management scheme with a well-defined interface between the parties, and efficient communication. In successful missions, each partner has had a clearly defined role and a real stake in the success of the mission.

5. *Sound plan for data access and distribution.* Cooperative ventures should have a well-organized and agreed-upon process for data calibration, validation, access, and distribution.

6. *Sense of partnership.* The success of an international space scientific mission requires that cooperative efforts—whether they involve national or multinational leadership—reinforce and foster mutual respect, confidence, and a sense of partnership among participants. Each partner's contributions must be acknowledged in the media and in publications resulting from joint missions.

7. *Beneficial characteristics.* Shared benefits such as exchanges of scientific and technical know-how and access to training are not usually sufficient justification in themselves to sustain an international mission. Successful missions have had at least one (but usually more) of the following characteristics:

- Unique and complementary capabilities offered by each international partner, such as expertise in specific technologies or instruments, or in particular analytic methods;
- Contributions made by each partner that are considered vital for the mission, such as providing unique facilities (launchers, space observatories, or laboratories), instruments, spacecraft subsystems, or ground receiving stations;
- Significant net cost reductions for each partner, which can be documented rigorously, leading to favorable cost-benefit ratios;
- International scientific and political context and impetus; and
- Synergistic effects and cross-fertilization or benefit.

8. *Recognition of importance of reviews.* Periodic monitoring of science goals, mission execution, and the results of data analysis ensure that international missions are both timely and efficient. This is particularly important if unforeseen problems in mission development or funding result in significant delays in the mission launch or if scientific imperatives for the mission have evolved since the original mission concept or development. A protocol for reviewing ongoing cooperative activities may avert the potential for failed cooperation and focus efforts only on those joint missions that continue to meet a high priority for their scientific results.

Recommendation 1

The joint committee recommends that eight key elements be used to test whether an international mission is likely to be successful. This test is particularly important in the area of anticipated and upcoming large missions. Specifically, the joint committee recommends that international cooperative missions involve the following:

- ***Scientific support through peer review that affirms the scientific integrity, value, requirements, and benefits of a cooperative mission;***
- ***An historical foundation built on an existing international community, partnership, and shared scientific experiences;***
- ***Shared objectives that incorporate the interests of scientists, engineers, and managers in common and communicated goals;***
- ***Clearly defined responsibilities and roles for cooperative partners, including scientists, engineers, and mission managers;***
- ***An agreed-upon process for data calibration, validation, access, and distribution;***
- ***A sense of partnership recognizing the unique contributions of each participant;***
- ***Beneficial characteristics of cooperation; and***
- ***Recognition of the importance of reviews for cooperative activities in the conceptual, developmental, active, or extended mission phases—particularly for foreseen and upcoming large missions.***

Planning and Identification of Cooperative Opportunities

Because planning, implementing, and managing are done by people, the findings and recommendations in the next two sections overlap somewhat with those in the section on personnel. Each area is vital. Even good people find it difficult to overcome poor planning. The joint committee found the following:

Finding: Planning for international missions has typically not been well coordinated with other related national programs or activities. Missions have been developed with similar, if not redundant, capabilities.

Recommendation 2

With respect to cooperation between NASA and the European Space Agency, the joint committee recommends that coordination between the planning and priority-setting committees of these agencies be enhanced to ensure that in an era of declining resources, missions are carefully considered to ensure their unique scientific contribution and global interdependence as well as their national impact.

Recommendation 3

Regarding cooperation between NASA and European countries, the joint committee recommends that scientific communities in the United States and Europe use international bodies such as the International Council of Scientific Unions (ICSU), the Committee on Space Research (COSPAR), and other international scientific unions to keep informed about planned national activities in the space sciences, to identify areas of potential program coordination, to discuss issues and problems (e.g., technology, data sharing and exchange, cultural barriers) related to international cooperation, and to share this information with national agencies.

Finding: Clear, open communications are particularly important for international missions in space science to ensure that the cooperative space efforts have clearly articulated common goals and responsibilities and that mission results will be freely available. Missions with active science working teams and external user committees provide the best communications both within the project team and with the greater community.

Furthermore, it is critical to foster an active sense of community with excellent communication among scientists, developers, engineers, and managers from all parties involved in carrying out the mission. Principal investigators[1] have experienced cases in which poor communication with managers and developers resulted in science return that was significantly below expectations. On the other hand, when scientists, developers, and managers were a true community, mission and instrument requirements were sharpened, design was improved, performance was excellent, and the science return met or even exceeded expectations. Such successful cooperation usually has involved a strong program scientist whose basic responsibility was to carry out the mission.

Recommendation 4

Given the important role that PIs in Europe and the United States have in leading and coordinating joint PI missions, the joint committee recommends therefore that for non-PI missions (in particular, multiuser ones such as those for microgravity research and life sciences and Earth observation), two program scientists of

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[1] For the purposes of this report, the following definitions are used:

- *Principal investigator:* a scientist who conceives of an investigation, is responsible for carrying it out, reports on the results, and is responsible for the scientific success of the investigation;
- *Program scientist:* a scientist who defines the policy and scientific direction of a program, establishes the mission science and applications objectives, and guides the science team to ensure that the scientific objectives are met;
- *Project scientist:* the scientist who leads a mission's science team and coordinates with the program/project manager to ensure that the science requirements of an investigation are met;
- *Program manager:* an individual responsible for cost, schedule, and technical performance of a multi- or single-project program and who oversees the project managers for integrated program planning and execution; and
- *Project manager:* an individual who manages the design, development, fabrication, and testing of a project.

stature, one U.S. and one European, be appointed at an early stage of joint planning to lead and coordinate the mission.

Recommendation 5

The joint committee recommends that only those international cooperative efforts be attempted in which participants consider themselves partners (even if their respective responsibilities and contributions are different) and have confidence in one another's reliability and competence as well as their dedication to the overall mission goals.

Management and Implementation

The management and implementation of cooperative missions rely not only on clearly established goals and rationale and good planning, but also on capable personnel. Similarly, poor management practices can significantly hamper even the most highly motivated team. The joint committee found the following:

Finding: A clear management scheme with well-defined interfaces between the parties and efficient communications is essential.

Recommendation 6

The joint committee recommends that, at the earliest stages of each international space research mission, the partners designate (1) two management points of contact, one U.S. and one European; (2) a project structure led by two designated PIs or program scientists, one U.S. and one European; and (3) an International Mission Working Group (IMWG) established with the two PIs or program scientists as co-chairs.

Finding: The lessons learned show the importance of defining a protocol for reviewing the ongoing cooperative activities by independent bodies, to ensure that these endeavors are both timely and efficient and that the criterion for high-priority scientific research is still met.

Recommendation 7

The joint committee recommends that each international mission in the space-oriented sciences be assessed periodically for its scientific vitality, timeliness, and mission operations, if a significant delay in mission development or if mission descope is necessary because of funding difficulties or other factors. For each cooperative mission, the participating space agencies should appoint a separate International Mission Review Committee (IMRC) composed of distinguished peers in science and engineering to review the overall vitality and value of the mission. The IMRC should be independent from the IMWG and the mission PIs. After the primary mission phase, the extension of mission operations and funding allocations from participating agencies for mission operations and analysis phases should be assessed by the IMRC.

Personnel

A prerequisite for good cooperative efforts between people is that they be recognized for their particular contributions, responsibilities, and roles (as noted also in the discussion in the section on management and implementation).

Finding: Experience shows that the roles and contributions of some partners in the success and results of a mission have not been sufficiently recognized or have even been overlooked in publications and in the media.

Recommendation 8

The joint committee recommends that the participation of each partner in an international space-related mission be clearly acknowledged in the publications, reports, and public outreach of the mission.

Finding: Those missions with the smoothest cooperative efforts had project managers on both sides of the Atlantic with mutual respect for each other. Clear scientific leadership is important for all types of missions. PI-type missions such as the Active Magnetospheric Particle Tracer Explorer (AMPTE) gained from having dedicated PIs maintain fundamental objectives and ensure data quality and distribution throughout the project.

Finding: Having assessed several cases, the joint committee found that even the best and seemingly most precise formulations of Memorandums of Understanding (MOUs) and other agreements may be subject to differences in understanding (especially in times of financial or political difficulties). This is often because of cultural differences or lack of effective communication between key individuals.

Finding: Because of the observed intellectual distance among scientists, engineers, and managers, good communication among these team members is an important ingredient of successful and smooth international cooperation. These interface problems are more critical in international cooperation, because of the added barriers of culture, language, and agency procedures that can further impede effective communication.

Recommendation 9

The joint committee recommends that program and project scientists and program and project managers be selected who have (1) a strong commitment not only toward the recognized mission objectives, but also toward international cooperation, and (2) excellent interpersonal skills, since it is important that key leaders and managers seek practical means for minimizing friction in joint U.S.-European missions.

Guidelines and Procedures

Finding: The joint committee found that international cooperation has been hampered by nonessential administrative requirements, lack of timely information on both sides of the Atlantic, and changes in budget policies.

There are many examples in which the two partners in a transatlantic cooperation succeeded, having overcome the difficulties imposed by their different selection and funding sequences. In the SOHO case, for example, there were points in the cooperative processes where agencies on both sides responded quickly and effectively to handle hardware problems, schedule delays, launch difficulties, and other unforeseen challenges in order to bring the mission and the cooperative effort to fruition. Other cases were not successful, and the envisaged cooperation did not materialize.

Recommendation 10

The joint committee recommends that NASA, ESA, and other international partners review their own internal rules and processes (particularly those that influence international collaboration and cooperation) and seek changes that might foster and improve opportunities for international cooperation. At a minimum, the agency partners should improve procedures so that the existing rules and processes can be more effectively explained to all participants. In particular, the necessary financial commitments should be provided on all sides, and contingencies should be agreed upon. These commitments must be made more stable, especially on the U.S. side.

Finding: International cooperation may be hampered by national interests and issues involving political, economic, and trade policies that may extend well beyond the boundaries of the individual space agencies involved:

- Export-import difficulties may affect the exchange of technology or technical information critical to a joint mission opportunity.
- Data exchange policies and commercial interests may also impede access to scientific data on cooperative missions.
- Laws governing intellectual property rights may restrict information flow or lead to difficulties in bilateral or multilateral U.S.-European space cooperation; and
- Failings within the MOU process can create delays, loss of scientific opportunities, lost economic investments, and a decline in international goodwill, all of which can weaken the foundation for future cooperative activities.

Recommendation 11

In light of the importance of international cooperative activities in space and given the changing environment for cooperation, the joint committee recommends that the national and multinational space agencies advise science ministers and advisers on the implications that particular national trade, export-import, data, and intellectual property policies may have on important cooperative space programs. As these types of problems on a particular mission arise, the agencies should encourage these ministers or advisers to bring such issues to the agenda of the next G-8 meeting.

Finding: To better phase the development of missions, the joint committee found that establishing milestone agreements in cooperative missions would be useful. The agreement between agencies (generally the MOU) is the key formal document defining the terms and scope of cooperation. Often, the comprehensiveness and clarity of this agreement have contributed significantly to the success of international cooperation in each discipline. Conversely, some of the difficulties encountered in several case studies can be traced in part to inadequate specificity in the agreement, or to misunderstanding or differing perceptions as to the status or interpretation of the agreement and the level of commitment implied by it. The observation that bilateral agreements between NASA and individual national space agencies appear generally less problematic than those between NASA and ESA may reflect the fact that NASA is itself a national agency, whereas ESA is a multinational organization with necessarily different perspectives. NASA-ESA cooperation refers to larger, more expensive, and more complex missions than cooperative activities between NASA and European countries.

The joint committee believes that the interests of all parties are best served when agreements have maximum clarity and specificity as to the scope, expectations, and obligations of the respective agencies and relevant scientific participants. Given the inevitable discrepancies between the procedures, practices, and budget cycles of NASA and ESA, the agreements must serve as essential interface control documents. Because the expectations and the level of commitment evolve as a mission is defined and developed, the need for written agreements also changes. Establishing clear agreements would be facilitated if NASA and ESA could agree on a set of generic mission milestones with clear definitions and on template agreements that certify the passage of such milestones, the anticipated progress toward the next milestone, and the expectations and time line for achieving it.

Recommendation 12

The joint committee recommends that for cooperative missions in space-based science NASA and ESA establish a clearly defined hierarchy of template agreements keyed to mutually understood mission milestones and implementation agreements.

A suggested example of a set of template agreements is given in Table ES.2, which describes a progression, with the Letter of Mutual Interest, Letter of Mutual Intent, Study MOU, and Mission MOU corresponding roughly to the usual Pre-phase A, Phase A, Phase B, and Phase C/D of space science missions. Only a fraction of missions would be expected to proceed through the full cycle, and each agreement could clearly state the likelihood of proceeding to the next stage.

Recommendation 13

In light of the continuing scarcity of future resources, the volatility of the U.S. budget process, and the importance of trustworthy international agreements supporting cooperative efforts in space, the joint committee recommends that international budget lines be added to the three science offices within NASA to support important peer-reviewed, moderate-scale international activities.[2]

[2] Although multiyear appropriations for international missions might be preferred, Congress has been reluctant to authorize such multiyear commitments because of the inflexibility it creates in the appropriations process.

TABLE ES.2 Hierarchy of Template Agreements for Cooperative Missions

Mission Phase	Agreement	Content
Pre-phase A	Letter of Mutual Interest	• Identify potential high-priority missions under consideration • Identify which bodies are studying them • Determine how many are likely to be confirmed, and when
Phase A	Letter of Mutual Intent	• Establish an early program management and project structure and an International Mission Working Group (IMWG) with two program scientists or principal investigators as co-chairs • Define objectives, scope, and expectations for Phase B • Review project management scheme
Phase B	Study Memorandum of Understanding (MOU)	• Clarify objectives and scope • Formulate anticipated implementation plan • Outline responsibilities • Select launcher • Provide a rough schedule • Determine expectations for funding
	Mission MOU	• Create full definition of objectives, scope, plan, schedule, contingencies, and data issues • Include project management plans
Phase C/D	Eventually, when necessary, appointment of an International Mission Review Committee (IMRC)	• Conduct periodic reviews of mission and effectiveness of its service to user community

Finding: The free and open exchange of data lies at the heart of international scientific cooperation.[3] When it is missing (as in the case of NASA and ESA in the area of Earth science) significant scientific international cooperation is difficult, if not almost impossible.

Recommendation 14

The joint committee recommends the following:

- ***NASA and European space agencies should make a commitment to free and open exchange of data for scientific research as a condition for international scientific cooperation after any proprietary period established for principal investigators;***
- ***The scientific community, through their international organizations (e.g., ICSU, COSPAR), should openly and forcefully state their commitments to this concept and where there are difficulties; and***
- ***U.S. and European space agencies should ensure that programs plan and reserve adequate resources for management and distribution of data and develop and implement strategies for long-term archiving of data from all space missions.***

[3] National Research Council, *Preserving Scientific Data on Our Physical Universe: A New Strategy for Archiving the Nation's Scientific Information Resources,* National Academy Press, Washington, D.C., 1995.

1

Introduction

THE JOINT COMMITTEE'S TASK

The Committee on International Space Programs (CISP) of the Space Studies Board (SSB) and the European Space Science Committee (ESSC) were charged by the National Research Council (NRC) and the European Science Foundation (ESF), respectively, with conducting a joint study on U.S.-European collaboration in space missions. The study was initiated jointly by the SSB and the ESSC after discussions over several years on the increasing importance of international activities and the need to assess previous experience. This study was conducted by a joint SSB-ESSC committee.

The joint committee's central task was to analyze a set of U.S.-European cooperative missions in the space sciences, Earth sciences from space, and life and microgravity sciences and to determine what lessons could be learned regarding international agreements, mission planning, schedules, costs, and scientific output. Although the charge is largely retrospective and relies on existing or past missions, the joint committee found that in some cases, missions in the development stage offered the best (or only) examples that met the study criteria set forth later in this chapter. The joint committee also determined that though a retrospective study was requested, lessons learned from the analyses must be considered within a prospective context to be relevant to future cooperative activities. Although many new cooperative U.S.-European programs are being planned, an analysis of these programs would be premature and beyond the scope of this study.

RATIONALE FOR INTERNATIONAL COOPERATION

The U.S.-CREST study[1] points out that over the years, space activities have been driven by four basic motivations: (1) national security and defense, (2) economic payoff, (3) new knowledge and experience, and (4) increasing the public good. As examples, the U.S. Apollo program was motivated primarily by the first, national security, including leadership and prestige. Communications satellites are perhaps the best examples of the second category, space activity for economic payoff. (Operational Earth observation satellites fall partly into the same

[1] U.S. Crest (Center for Research and Education on Strategy and Technology), Partners in Space, *International Cooperation in Space: Strategies for the New Century,* Arlington, Va., May 1993, p. xiii.

category.) Space and Earth science programs conducted from space are the foremost examples of the third motivation, and meteorological satellites are an excellent example of the fourth.

From the perspective of international cooperation, it is important to note that there tends to be less difficulty when the motivations of the cooperating partners are the same, or at least known to each other and compatible. An in-depth assessment of the basic motivations for cooperation and agreement on objectives, share of responsibilities, schedule, and financial framework is a precondition to the success of any cooperative effort, particularly any large-scale one. Such an assessment allows for effective, realistic negotiations before the program begins, although this may not suffice, as discussed in detail in Chapter 3.

Among the reasons for international cooperation in the space sciences are the following:

- Improved scientific results from the sharing of experience, resources, data, and knowledge;
- Enhanced and diversified opportunities for space research;
- Reduction of costs for each participant through cost sharing. Cost sharing has generally included in-kind payments such as payload launches, instruments or facilities, operations support, tracking, and data collection and dissemination;
- Enhanced chances of obtaining program or project approval and seeing it through to a successful conclusion;
- Provision of access to unique capabilities, facilities, or locations;
- Stimulation of technology development;
- Access to new technologies; and
- Improved international relations.

As a result of these incentives, space science has enjoyed a particularly long history of cooperation. Indeed, the entire space science program began as a cooperative effort with the 1957-1958 International Geophysical Year. This report furthers the interest in cooperation by deriving lessons learned as to why some U.S.-European cooperative efforts have been more successful than others. From these lessons learned, the committee hopes to improve international cooperation in the future and to enable better use of the available funds for space research. The heart of the report is a set of case studies of cooperative space science missions conducted in a "bottom-up" manner with the collaboration of European and U.S. officials who were actively engaged in carrying them out. The case studies are divided into three areas: classic space science,[2] Earth science conducted from space, and microgravity research and life sciences (MRLS; see Box 1.1). This allowed the committee to compare the similarities and differences among these studies in terms of boundary conditions, substance, and procedure. The unique aspects of each of these three areas are significant and warrant individual investigation.

SCOPE AND STUDY CRITERIA

It is recognized that cooperation in space research occurs worldwide, with notable contributions from many countries. From this broad view, U.S.-European cooperation is a subset (albeit an important one) of the whole. This study focuses on the United States and Europe because of the long history of cooperation between the two. They present a complex history of variables to analyze and understand (particularly when programs with individual European countries are included) and can provide lessons for the wider community as well. Further study of the more far-reaching aspects of cooperation that are not included here, as well as experiences acquired through cooperation with such space-faring partners as Japan and Russia, may be undertaken in the future.

Technically, *cooperation* means combining the efforts of two or more countries in an integrated project (large or small) to reach a common set of objectives; *coordination* means linking two or more relatively independent projects to enhance their scientific return; and *collaboration* means joining the efforts of two or more scientists or other individuals to achieve a common set of objectives. For the purposes of this report, however, cooperation is used as a generic term denoting international participation in a project.

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[2] Classic space science includes space physics, astrophysics, astronomy, and solar system research.

BOX 1.1 Case Study Areas

Classic Space Science

Space science is a traditional scientific activity whose objective can be accomplished only in space or by observations from space. Space sciences are those that, through the data from spaceborne instruments, further the study of Earth's environment above the atmosphere, the exploration of the solar system, the study of celestial bodies and their evolution, and the study of cosmological questions about the beginning, evolution, and future of the universe, including the possibility of life elsewhere. Spaceborne instruments permit in situ measurements of Earth's space environment, access to wavelengths and energetic particles of galactic and solar system origin blocked by the atmosphere, freedom from atmospheric aberration, and long observing times. Space sciences include the exploration of the Sun and of the interplanetary medium. Space science has been a pathfinder of international space activity. It has a highly structured community with a tradition of cooperation across national boundaries unhindered by political or commercial considerations. Its technical tools, spacecraft, and instruments present a continuous challenge to scientists and engineers alike in the incessant pursuit of the elusive knowledge of the workings of our universe.

Earth Science Conducted from Space

Earth science seeks to develop our knowledge of planet Earth and its response to natural and human actions. The disciplines concerned are diverse and include the atmospheric sciences (physics, aeronomy, and chemistry); oceanography (physics, chemistry, geology, and biology); and land surface studies (physics, chemistry, biology, engineering, geology, geography, and glaciology). There is no unified Earth science community, although all disciplines recognize that interactions among these fields are essential; for example, general circulation models can couple the atmosphere, ocean, and land. Moreover, Earth sciences research can be conducted using data from ground-based investigations or from space-based Earth observations. Earth science conducted from space has multiple objectives: scientific, operational, commercial, political, and military. National interests may provide reasons for space-based Earth observation missions that complicate international cooperation in both the definition of mission goals and the legal and national security considerations. On the other hand, for a given mission the set of data acquired may be appropriate for several of the above-mentioned objectives and may be shared among different discipline teams. The possibility of using space-based Earth observation data for commercial or national security applications may have a strong impact on data policies, which may differ among countries. Unlike the space sciences, Earth observations from space also make it possible to perform control, validation, and calibration experiments in the field, which can be blended with a variety of data types for analysis.

Microgravity Research and Life Sciences (MRLS)

Microgravity research and life sciences (MRLS) is a term that covers a broad group of disciplines. What they have in common is the fact that gravity is an important parameter and that the lack of gravity in space allows experiments to be conducted that could not be performed on Earth. In general, microgravity research and life sciences are laboratory sciences. On the physical side, MRLS involves studies of the effects of gravity on chemistry, physics, combustion science, materials science, and fluid science. In the life sciences, MRLS includes studies of the effects of gravity on human physiology and of the basic biology of plants, animals, and microorganisms. In addition, MRLS research studies the effects of radiation on living organisms. MRLS studies in space usually consist of a large number of small, relatively short-term experiments, which must be replicated as often as possible. Some experiments are designed to learn about the specific effects of gravity on processes or organisms. Others are designed to take advantage of the lack of gravity in space. Some MRLS experiments are autonomous or can be operated remotely, but most require manipulation by humans during the course of the experiment. As a result, most MRLS experiments can be performed only aboard a spacecraft with a crew.

More than a hundred missions have involved various levels of U.S.-European cooperation in space research, some of which vary greatly in scope, complexity, and the types of cooperation and management approaches used. Some missions were quite successful, others failed, and several projects never achieved fruition. It was therefore impossible to review and analyze all of these missions within the scope of this report. The joint committee decided to restrict the study to the following:

- Past missions that could be extended to missions in the development stage when no other examples were available or when the missions illustrated specific lessons learned;
- Missions resulting from cooperation between the National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA) or between NASA and one or several European nations;
- Missions that differed in scope and complexity, from principal investigator (PI)-type to multipurpose and observatory types;[3]
- Missions corresponding to different types of cooperation; and
- Cooperative efforts that succeeded and those that failed.

It is clear in retrospect that the types of cooperation that have taken place have been largely dependent on the technical maturity of the respective participants and the political and economic environment. Therefore, a synopsis of each to establish historical context is necessary.

The remainder of this report contains three chapters. Chapter 2 gives an overview of past cooperation in space research between the United States and Europe. Its aim is to provide the reader with a feeling of the importance of U.S.-European cooperation, to establish the context of its evolution, and to identify how cooperation is established and fostered. Thus, Chapter 2 sets the stage for this study. It turns out that the different structures within which agencies operate and each agency's particular funding and decision-making processes play very important roles. They are therefore presented at the end of Chapter 2 to give a complete picture of the importance of U.S.-European cooperative efforts.[4]

Chapters 3 and 4 are devoted to the analysis of missions and the identification of the most significant lessons learned, from which recommendations are made to improve cooperation in future missions. Because it is not possible to analyze all of the missions introduced in Chapter 2, Chapter 3 is limited to the analysis of carefully selected missions that represent typical case studies. It gives the rationale for selecting these case missions and the guidelines for studying them. To keep Chapter 3 at a reasonable length, it contains only a short description of the missions selected and of the story behind each cooperative effort.

Chapter 3 goes from analysis of the missions to the lessons learned (or findings) per discipline, and Chapter 4 identifies the key factors common to all of these findings, whatever the discipline. Restructuring the findings of Chapter 3 according to these key factors leads to the recommendations in Chapter 4.

[3] A PI mission is one in which the primary responsibility for instrument design and for the production of data is in the hands of a principal investigator(s). Most smaller missions are conducted in this mode, but larger missions (e.g., Upper Atmosphere Research Satellite [UARS]) can be PI missions as well. The classic example of a facility or observatory-class mission is the Hubble Space Telescope (HST), which is a facility that investigators propose to use. There also are hybrid missions of each type.

[4] Tables A.1 through A.3 listing missions realized in the framework of U.S.-European cooperation are presented in Appendix A.

2

Historical Context of U.S.-European Cooperation

This chapter describes the historical context for cooperation in space science between the United States and Europe. The development of U.S.-European cooperation in space science is discussed in four stages: 1958-1973, 1974-1982, 1983-1992, and a fourth stage referred to as the post–Cold War period.[1] The chapter also recognizes that cooperation developed in different ways and at varying rates for space sciences, Earth science, and microgravity research and life sciences (MRLS) because of their unique characteristics and traditions. This historical context sets the stage for the analysis of a small set of missions from which important lessons can be learned on how to improve future international cooperation.

Most of the early international cooperation in the space sciences was between the United States and Europe. Between 1958 and 1983, 33 of the 38 National Aeronautics and Space Adminstration (NASA) cooperative spacecraft projects were conducted with European entities, and 52 of 73 experiments with foreign principals involved Europeans.[2] For the most part, the experience has been extraordinarily successful. However, some lessons have helped both sides learn how to better maximize a project's probability of success. The objective of this review of the U.S.-European experience is to clarify how the United States and Europe might expand and improve cooperation in space.

CHRONOLOGY

1958-1973

The U.S. Perspective

The U.S. position on space cooperation was first officially stated in the U.S. National Aeronautics and Space Act of 1958, which is essentially the NASA charter. Included in its objectives is the following: "Cooperation by the United States with other nations and groups of nations in work done pursuant to this Act and in the peaceful

[1] Selection of the first three periods discussed in this chapter was based on a lecture by Reimar Lüst, "The Cooperation of Europe and the United States in Space," Fulbright 40th Anniversary Lecture, April 6, 1987, Washington D.C., p. 5. According to Lüst, these phrases are not unique to space but in fact have been evidenced in other areas of science as well, such as high-energy and elementary particle physics or plasma physics. The lecture is reprinted as Lüst, R., "Cooperation between Europe and the United States," *ESA Bulletin*, May 1987, pp. 98-104.

application of the results thereof."[3] To its credit, NASA has actively embraced this objective for many years. The political environment within which cooperation has taken place, however, has helped determine what types of cooperative efforts would be supported by involved governments and where they would be conducted.

The reasons for an international approach to space activity from the U.S. perspective in the early years were quite clear. The more pragmatic reasons focused on the U.S. requirement for worldwide tracking locations. NASA wanted to create an international climate in which other countries would be favorably disposed toward allowing tracking sites on their territory.[4] Beyond this immediate need, international cooperation helped promote certain economic and political objectives. The United States, for instance, wanted to create global markets for newly emerging communications and aerospace industries.

During the Cold War there was significant political goodwill to be gained by the United States through cooperation with Europe vis-à-vis the former Soviet Union. The NASA Task Force on International Cooperation in fact stated in 1987 that "international cooperation in space from the outset has been motivated primarily by foreign policy objectives."[5] Competition in space (including the space sciences) was part and parcel of concerted efforts made by the superpowers to convince other countries of their technical capabilities, and hence leadership. This leadership aspect was at one time sufficient reason to engage in a cooperative activity.

Finally, there were also scientific and technical objectives for cooperating. In this initial period, the benefits of technology acquisition flowed primarily from the United States to other countries. The United States, although willing to be (and indeed seeing benefit in being) generous in its cooperative efforts, nevertheless attempted to avoid unnecessary technology transfer. Space science, as a field within space activity, was deemed a benign and nonthreatening field for initial cooperative efforts.[6]

Basic scientific research, as opposed to applied science, has traditionally been considered a field in which open, cooperative work should be encouraged. Further, the desire of members of the international scientific community to work together to maximize the benefits accrued from each scientific effort engendered a unity of purpose that transcended national boundaries. During the first stage of U.S.-European cooperation, space science was therefore actively pursued as a cooperative venture. The initial guidelines set by NASA for cooperation were simple: [7]

- Having each participating government designate a civil government agency for the negotiation and supervision of joint efforts;
- Conducting projects and activities having scientific validity and of mutual interest;
- Agreeing on specific projects rather than generalized programs;
- Having each country accept financial responsibility for its own contributions to joint projects (no exchange of funds); and
- Providing for the widest and most practicable dissemination of the results of cooperative projects.

The focus of the guidelines reinforces the statement that scientific cooperation was what the United States envisioned; thus, cooperative space efforts took on multiple forms relatively quickly. These forms ranged from handshakes in space, with Apollo-Soyuz, to Spacelab and the International Space Station (ISS). The difference between what was originally envisioned and what eventually transpired was largely determined by fluctuating economic conditions as well as national interests.

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[2] Logsdon, J.M. "U.S.-European Cooperation in Space Science: A 25-Year Perspective," *Science* 223:11-16, January 6, 1984.

[3] Public Law 85-568, National Aeronautics and Space Act of 1958, July 29, 1958.

[4] Marcia S. Smith, "America's International Space Activities," *Society* 18 (January-February), 1984. Actually there were four tracking programs being established: (1) mini-track, a north-south network throughout the Western hemisphere for scientific satellites; (2) the deep-space network; (3) the manned spaceflight ground stations; and (4) the Baker-Nunn (named for the camera design used) tracking stations for a Smithsonian astrophysics program.

[5] Task Force on International Relations in Space, National Aeronautics and Space Administration, *International Space Policy for the 1990's and Beyond*, NASA, Washington, D.C., October 12, 1987, p. 18.

[6] In his book *Science with a Vengeance,* David DeVorkin presents an interesting history of the linkage between early military space operations and space science. DeVorkin, D., *Science with a Vengeance*, Springer-Verlag, New York, 1993.

[7] Division of International Affairs, National Aeronautics and Space Administration, *26 Years of NASA International Programs,* NASA, Washington, D.C., January 1, 1984, p. 2.

This initial period encompasses the so-called Golden Age of the U.S. space program. It was dominated by the space race, with the United States having one key opponent and several peripheral players anxious to build their capabilities. Although the United States was competing with the former Soviet Union, it was seeking benign ways to cooperate with other nations. Because of the self-imposed Soviet isolation, the United States was able to assume a mentoring role with these other countries. The Cold War with the Soviets led the United States to want an open program, but a controlled one, so that military security and technology could be protected. For this reason, the guidelines and policies for international cooperation (even in science) were set not so much by the science community as by government science and security policy administrators, with a view toward keeping a balance between openness and U.S. security interests.[8]

The European Perspective

The European position actually begins from multiple national perspectives, rather than a single unified one. Involvement in the space program was considered essential, and the motivation for participation was simple: "the early realization that space activities might lead to advances in technology that could be important in the resurrection of Europe's economic and industrial development."[9] Indeed, Europe considered it imperative to avoid a "technology gap" with the United States and saw space as a primary technology generator.[10] Space meant technology and technology meant industrial development, which in turn meant economic growth. There was no doubt about Europe's pragmatic motivations for entering the space arena or its long-term intentions.

European goals were initially pursued through bilateral agreements with the United States, particularly by France, the United Kingdom, and Italy, where substantial national programs were already coming of age (Box 2.1). After the launch of Sputnik by the former Soviet Union and the rapid start-up of the U.S. program, it became apparent that the efforts of individual nations were inadequate to meet the increasing capabilities of the superpowers.[11] The alternative was to create European space entities that would allow Europe to speak with one voice to the two leading space powers and, at the same time, build a competitive space program. Originally, those in Europe leaned toward creating two organizations—one entity dedicated to the development of launchers and one dedicated to space research—because of concerns that launcher development would repress scientific efforts and that regional cooperative effort would supplant national activities. The European Launcher Development Organisation (ELDO) and the European Space Research Organisation (ESRO) were subsequently chartered in 1964.

Most Europeans acknowledged that there was only one road toward building a mature space program—working with the United States. Therefore, just as cooperation among European countries had proven necessary, so too had cooperation with the United States.[12] It is interesting that during this time, European countries acquired more experience working with the United States than with each other, and consequently within Europe there were some difficult learning experiences.[13] Working with the United States through bilateral agreements for experiments to be flown by NASA or for data exchange or guest investigator programs (and later, the launching of European spacecraft by NASA)[14] proved less complex than multilateral European cooperation arrangements.

At the close of this first stage (see Box 2.1), the plan for NASA's post-Apollo program consisted of a large, multimodule space station, a reusable transportation system (the Shuttle), and an interorbital tug to operate in

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[8] Johnson-Freese, J., *Changing Patterns of International Cooperation in Space,* Orbit Book Co., Malabar, Fla., 1990, pp. 4-5; Logsdon, "US-European Cooperation in Space Science," p. 12.

[9] Bonnet, R., and Manno, V., *International Cooperation in Space: The Example of the European Space Agency*, Harvard University Press, Cambridge, Mass., 1994, p. 3.

[10] See Servan-Schreiber, J.J., *The American Challenge,* Avon Books, New York, 1967; William, R., *European Technology: The Politics of Collaboration*, Croom, Helm, Ltd., London, 1973.

[11] Krige, J., *The Prehistory of ESRO 1959/60* (ESA HSR-1), European Space Agency, Paris, July 1992, pp. 2-4.

[12] Johnson-Freese, *Changing Patterns of International Cooperation in Space,* pp. 11-13.

[13] Krige, J., "The Rise and Fall of ESRO's First Major Scientific Project, the Large Astronomical Satellite (LAS)," in *Choosing Big Technologies*, J. Krige, ed., Harwood Academic Press, London, 1993, pp. 1-26.

[14] For a detailed history see Sebesta, L., *United States-European Cooperation in Space During the Sixties* (ESA HSR-14), European Space Agency, Paris, July 1994.

BOX 2.1 U.S.-European Cooperation: 1958-1973

Space Sciences

During this first period, international cooperation in space science was a means to a political end for the United States, as well as a way researchers could increase scientific return on a specific activity or experiment. Scientists had increasingly recognized the benefits of working together, particularly after earlier efforts undertaken in conjunction with the International Geophysical Year (July 1957-December 1958). They saw that together they could achieve more using fewer individual or national resources. Although nationalistic concerns were not forsaken, national and international efforts were combined in various ways, with a deliberate attempt to integrate them into long-term international planning.

Before the creation of any European space organization (i.e., between 1958 and 1964), U.S.-European cooperative missions were initiated bilaterally, beginning with the early Ariel missions with the United Kingdom from 1962 to 1964, the first San Marco satellite with Italy and the Explorer 20 mission in 1964, the FR-1 mission with France in 1965, and the Orbiting Solar Observatory (OSO) mission with the United Kingdom and France in 1965 (with the second OSO mission following in 1967). Between 1962 and 1964, the ESRO and ELDO conventions were signed but not ratified. Multilateral U.S.-European cooperation therefore commenced on an unofficial basis and expanded after 1964 with the establishment of ESRO. For ESRO, NASA launched ESRO-II in May 1968 and ESRO-I in October 1968. The ESRO-II mission was an integrated study of solar radiation and cosmic rays, and ESRO-I was an integrated study of high-latitude energetic particles and their effects on the ionosphere. After 1975, the European Space Agency (ESA) replaced ESRO and ELDO, and ESA-NASA cooperation began. There has been bilateral and multilateral cooperation on science payloads since 1958, which continues today.

Earth Sciences

In the area of Earth observation, remote sensing from space began with the launch of Tiros 1 in 1960, which brought views of Earth's cloud cover to Earth. Tiros 1 was so successful that plans for an advanced research meteorological system were considered almost immediately. The first Nimbus was launched in 1964, becoming the test-bed platform for meteorological observations, with Tiros developing into the operational system. The Tiros satellites carried an Automatic Picture Transmission (APT) system that allowed for direct readout of meteorological data. European countries began accessing APT data in the early 1960s; this stimulated the development of an Earth science community in Europe, much as in the United States. Following the early success of the Tiros and Nimbus series, the scientific community began planning an array of Earth observation missions ranging across the spectrum of Earth science and applications. Applications, however, became the principal rationale for funding land remote sensing in the early period, whereas Earth science and technology focused on understanding what was being observed in various spectral regions and providing the space hardware.

This possibility of Earth remote sensing particularly excited the geological community and a broad base of agriculture, timber, and water resource managers as well as engineers and business leaders with specific interests in land-based opportunities who saw useful applications of the technology. The U.S. Department of the Interior responded quickly to the new opportunities presented by land remote sensing from space and requested funding in 1968 for a long-range mission: the Earth Resources Observation Satellite (EROS). It was denied largely because the U.S. Department of Agriculture sensed the importance of this new technology and did not want the market cornered by mineral and water applications, and also because NASA did not want another civil agency to be empowered to conduct space missions. The administration settled this bureaucratic debate in NASA's favor. Thus, in 1972, NASA launched Landsat 1 (originally named the Earth Resources Technology Satellite) as an experimental research activity to explore the use of multispectral imagery of Earth's surface. Landsats 2 through 5 followed in 1975, 1978, 1982, and 1984.

An important aspect of U.S.-European cooperation in Earth science during this period was the launching of the Eole/FR-2 in 1971, preparatory work for which began in 1968. It was a NASA-CNES (Centre National d'Études Spatiales) cooperative mission to determine the location of balloons flying in the atmosphere of

(continued)

BOX 2.1 (Continued)

the Southern Hemisphere and, hence, to measure winds. The important aspect is that Eole was in fact the precursor of the Advanced Research and Global Observations Satellite (ARGOS) localization system, which became operational on National Oceanic and Atmospheric Adminstration (NOAA) satellites. At that time, France was initiating studies for development of the European Geostationary Meteorological Satellite (METEOSAT), later proposed and accepted as a European program.

Microgravity Research and Life Sciences

Before 1970, there were no significant international programs in microgravity research and life sciences. In 1972, cooperation in the life sciences began with experiments on Apollo 16 and 17 on the Biostack I and II facilities. Biostack was a nuclear track detector system consisting of multilayers of thin plastic foils interspersed with monolayers of suitable microbiological organisms. The assembly allowed for the registration of tracks, especially of HZE (high-charge *Z* and high-energy) particles, with respect to the position of individual cells. The Apollo experiments allowed the direct action of HZE particles on individual cells to be studied for the first time. [1]

[1] Buecker, H., and Horneck, G., "Studies on the Effects of Cosmic HZE-Particles on Different Biological Systems in the Biostack Experiments I and II Flown on Board Apollo 16 and 17," in *Radiation Research: Biomedical, Chemical, and Physical Perspectives*, O.E. Nygaard, ed., Academic Press, New York, 1975, pp. 1138-1151.

conjunction with the Space Station. This program included international cooperation as a deliberate policy meant to attract resources from other countries, particularly European ones. Involving other nations would also broaden the program's political base in the United States and help alleviate the financial burden. Quite apart from the substantial political, industrial, and financial implications that such participation would have on the evolving European space program, NASA's offer represented a new approach to cooperation because it foresaw Europe's substantial involvement. Europe studied different options. In the meantime, the large Space Station concept was dropped from the U.S. program, and the Shuttle was extensively redesigned. (A single-module manned space station, Skylab, was successfully orbited and operated for several years.)

On the U.S. side, the demise of the Space Station stimulated interest in finding the best possible replacement. This took the form of a space laboratory, or Spacelab, to be carried in the Shuttle cargo bay. NASA's emphasis on Spacelab, however, diminished interest in the tug, which had become particularly enticing for Europeans because of Europe's interest in developing the tug's technologies and in providing for its operational use. However, within European countries, there were widely diverging views, since it was clear that substantial participation in the space tug program would affect the possibility of European developments in the field of launchers and application satellites.[15] The controversy over the availability of American launchers for European telecommunications satellites and the intervening negative stance NASA took on a European tug heightened interest in European efforts at launch autonomy.[16] The modes of cooperation in the NASA program thus shifted toward the reusable laboratory, subsequently renamed Spacelab. The historic European Ministerial Conference in December 1972 sealed a package deal including four decisions: (1) the merger of ESRO and ELDO into a single European Space Agency (ESA); (2) the development of Spacelab; (3) the development of an independent European launcher, later named Ariane; and (4) the development of the maritime satellites, Marots.[17] The conference represented a turning point

[15] Sebesta, L., *United States-European Space Cooperation in the Post-Apollo Programme* (ESA HSR-15), European Space Agency, Paris, February 1995, pp. 38-46.

[16] Sebesta, L., *United States-European Cooperation in Space During the Sixties* (ESA HSR-14), European Space Agency, Paris, July 1994, pp. 28-29.

[17] Russo, A., *The Definition of a Scientific Policy: ESRO's Satellite Programme in 1969-1973* (ESA HSR-6), European Space Agency, Paris, March 1993, p. 45.

and had a lasting influence on the relationship between the United States and Europe and the respective positions they took in the space arena.

1974-1982

The second period of U.S.-European cooperation begins with Europe having a significantly matured, truly integrated regional program. For NASA, the post-Apollo period was one dominated by a search for a raison d'être in the face of less money and less political support. NASA had achieved the foreign policy goal of reaching the Moon, a goal it had been presented by the U.S. government and the American people, and then found itself to be a bureaucracy without clearly stated goals and objectives for the future.

The U.S. Perspective

The flagship of NASA's post-Apollo program was the Shuttle. With the original approval of the Shuttle had come a new demand for cost-effectiveness and return on investment. The Shuttle was promoted by NASA as a vehicle to bring down costs and increase efficiency because it could be reused. Prestige, leadership, and human destiny were no longer sufficient motivations for large government expenditures toward civil space ventures. It is ironic that the United States was moving toward the pragmatism that had earlier spurred the Europeans to engage in space activities.

Aside from the move toward cost-efficiency and justifiable expenses, NASA, as an agency, lacked clearly stated goals and objectives for the U.S. crewed space program during the post-Apollo period. In the absence of overall agency direction, the Shuttle became a transportation system without destinations or predetermined passengers. To make the Shuttle more cost effective (in response to congressional pressure), NASA sought to focus all significant access to space on the Shuttle vehicle. Space scientists were therefore forced to design their experiments and spacecraft for Shuttle launch. As a result, the debate over crewed versus uncrewed missions in the space sciences, having emerged during the Apollo period, was once again at the forefront. Moving all NASA spacecraft to the Shuttle also created a dependence on the Shuttle and thus encouraged a "single-point failure" for the U.S. space program. Although the crewed mission program was having difficulty, NASA had some spectacular successes in its uncrewed missions, as evidenced by the Voyager program and the International Ultraviolet Explorer (IUE), which had international participation.

The American public gave strong rhetorical support to space activity, but in competition with other areas of funding, civil space efforts were often considered expendable (or at least protractible). NASA increasingly began looking to international participation as a way to strengthen its own uncertain domestic financial position. For the first time, encouraging international participation as a way to bolster political support for a program domestically began to rival promoting science as the principal rationale for international cooperation. Internationalizing a space program became an attempt to lend it stability and a higher degree of assurance of continuity than was available to strictly national programs. But this strategy would later prove problematic.

The European Perspective

Development of the Shuttle gave other countries the opportunity to participate in more fundamental cooperative roles, where previously cooperation had primarily meant having NASA launch a foreign spacecraft or placing an experiment on board one of NASA's. In the Shuttle program, full pieces of hardware were contributed by both Europe and Canada, with Europe providing Spacelab and Canada the robotic arm for the Shuttle. This new willingness of the United States to involve others in the development of key components of a U.S. system reflects changing U.S. economic and political imperatives and has been characterized as being a reaction, at least in part, to "sensitivity to the criticism that she [sic] aspired to technological domination of the Old Continent."[18] Initially,

[18] Krige, J., and Russo, A., *Europe in Space 1960-73* (ESA-SP1172), European Space Agency, Noordwijk, The Netherlands, 1994, p. 84.

BOX 2.2 U.S.-European Cooperation: 1974-1982

Space Sciences

In this second stage, the ESA science program evolved into a largely independent one, with purely European projects such as the two GEOS (geostationary satellites), the two Highly Eccentric Orbit Satellites (HEOS), the Cosmic Ray Satellite B (COS-B), and the European X-Ray Observatory Satellite (EXOSAT) missions. Only two projects were conducted in cooperation with NASA: the International Sun-Earth Explorer (ISEE) and the International Ultraviolet Explorer (IUE), with ESA in the position of junior partner. Several European countries participated in bilateral projects such as AEROS (United States-Germany), Helios (United States-Germany-Italy), IUE (United States-ESA-Great Britain), High Energy Astronomical Observatory (HEAO; France-Germany), Solar Maximum Mission (SMM; United States-Netherlands-Great Britain), Infrared Astronomical Satellite (IAS; Netherlands-United States-Great Britain), Orbiting Astronomical Observatory (OAO-2), Copernicus (United States-Great Britain), Astronomical Netherlands Satellite (ANS; Netherlands-United States) and Active Magnetospheric Particle Tracer Explorer (AMPTE) (United States-Germany-Great Britain). However, major future cooperative efforts between ESA and NASA were negotiated in earnest during this period, namely the International Solar Polar Mission (ISPM) project (later renamed Ulysses),[1] the Hubble Space Telescope (HST), and a joint cometary mission. From the viewpoint of the learning process on NASA-ESA cooperation, this period is highly significant. These three NASA-ESA projects were all of great scientific value; the motivations for cooperation were the same; and all foresaw a substantial involvement of ESA, but each led to quite different results.

Earth Sciences

During this period, U.S.-European cooperation in Earth science from space focused mainly on data analysis. This gave both U.S. and European scientists the opportunity to build a common heritage of knowledge and practice.

For instance, the cooperation between the United States and Europe in the field of spaceborne thermal infrared and microwave remote sensing started with the Heat Capacity Mapping Mission (HCMM) and the Seasat project, respectively. Seasat, launched on June 27, 1978, was the first American satellite dedicated to studying the ocean surface. It carried a suite of microwave sensors, including a radar altimeter, synthetic

European proposals presented after Apollo were rejected by the United States as involving too much (or too sensitive) advanced technology. Spacelab, which was eventually approved by the United States, was, from the European perspective, "a project not without interest but, as far as technological sharing was concerned . . . a far cry from what the Europeans had hoped for when the negotiations got under way in 1969."[19]

The Spacelab experience was certainly a technical success.[20] Whether each side got what it expected politically or economically is debatable. If NASA had bought three or four Spacelabs, allowing Europe to set up a production line, the Europeans would likely have viewed it as a success. When NASA bought only one, some considered it an economic and political disaster for Europe and especially for Germany, the European lead on the project. The need to clearly define goals and expectations in cooperative ventures so as to avoid misunderstandings later was becoming increasingly apparent.

See Box 2.2 for summary of U.S.-European cooperation during this period.

[19] Krige and Russo, *Europe in Space 1960-73*, p. 84.
[20] See Lord, D.R., *Spacelab: An International Success Story,* National Aeronautics and Space Administration, Washington, D.C., 1987.

aperture radar (SAR), a wind scatterometer, and a multichannel microwave radiometer. Nimbus 7 was launched the same year, the last of the Nimbus series, providing the first ocean color measurements and the first daily mapping of ozone concentrations.

European scientists from 30 European laboratories working in remote sensing formed SURGE (Seasat Users Research Group of Europe) in 1977 and persuaded ESA to build a receiving station for Seasat in Oakhanger, England. Seasat data received at Oakhanger were extensively analyzed by European scientists. In particular, oceanographers extracted a wealth of information from these data. The highly successful U.S.-European cooperative effort on the Seasat project eventually triggered the European Earth Remote Sensing (ERS) satellite project.

From a European perspective, Earth observations began during this stage. ESA launched its first Earth observation satellite, METEOSAT, in 1977, which contributed to both the Global Atmospheric Research Program (GARP) and the World Weather Watch (WWW). Later, when one of the U.S. geostationary weather satellites failed, a European METEOSAT satellite was lent to the United States to provide coverage of the Western Hemisphere and maintain WWW. ESA also started distributing Earth observation data from U.S. sources and providing European ground stations (e.g., for the HCMM and Landsat).

Microgravity Research and Life Sciences

Between 1974 and 1982, there were only limited international MRLS experiments in space. These used various facilities on the Shuttle and Soyuz, including Biostack. However, in this post-Apollo era, NASA decided that a more effective way of carrying out significant levels of MRLS experiments was needed. It decided to make use of a dedicated flying laboratory that could be transported to low Earth orbit on the Shuttle and could be used frequently for a multitude of experiments of different types. This was Spacelab, the European-provided laboratory module, which fitted into the Shuttle cargo bay and could be adapted for a wide variety of life science or microgravity science experiments by interchanging the equipment that it carried on board.

[1] The International Solar Polar Mission (ISPM) was renamed Ulysses by ESA in 1986, following NASA's withdrawal as a major partner and the switch from a dual-spacecraft to a single-spacecraft mission.

1983-1992

The third period begins in 1983 with the first operational launch of Ariane and an era of competition and partnership between Europe and the United States. The entry of the Ariane launcher into the commercial field ended the U.S. monopoly in commercial launch services. Focus on the Shuttle continued NASA's single-point failure mode of operation and led to the virtual reshaping of the agency.

The U.S. Perspective

During his first term in office President Reagan began to view space as an integral part of his technology-building campaign to put strong military and budgetary pressure on the Soviet Union and to strengthen the United States economically. Subsequently, he initiated multiple new large-scale space efforts, including the Strategic Defense Initiative (SDI) in 1983, the Space Station in 1984, and the National Aerospace Plane in 1986. Rhetorical support did not translate into program commitment, however, and the programs were faced with multiple political challenges. These efforts coincided with a push toward space commercialization, evidenced by NASA's creation of the Office of Commercial Programs in 1984. By the time the Space Shuttle became operational, the earlier emphasis on return on investment had evolved into one of "space for profit." Unfortunately, it became difficult to maintain the premise and image of an active space program headed toward commercialization when the entire U.S. space fleet was basically grounded by spring 1986.

Politically, NASA could not escape a managerial, technical, and political tragedy of the dimension of *Challenger* unscathed. NASA's very integrity and capabilities were being questioned in the media. Criticism of NASA became almost a national pastime. Shuttle flights were halted until the cause of the accident—the O-ring problem—could be identified and corrected. The prior policy of forcing as many missions as possible onto the Shuttle to maximize the number of flights and spread the heavy overhead costs over as many launches as possible was reversed. Payloads were off-loaded to expendable launch vehicles, which suddenly were in short supply. (The military, however, had succeeded in acquiring funds for additional expendable launch vehicles, deciding earlier that the Shuttle was not reliable enough to be the sole carrier of their mission-critical satellites.) All of this caused lengthy delays for important national and international missions and drove up Shuttle costs substantially. At the same time that NASA was facing unprecedented domestic pressure as a result of *Challenger*, it was also under enormous pressure from abroad. Space had gone from being an elitist field dictated by the political aims of the superpowers to a pluralist community of competent players engaging in a variety of commercial and civil endeavors. NASA was facing competition and criticism on many fronts, and it was neither prepared for nor accustomed to such reactions.

The European Perspective

From its inception, ESA was conceptually separated from operational activities. The official statement of purpose in the ESA Convention reads: "The purpose of the Agency shall be to provide for and to promote, for exclusively peaceful purposes, cooperation among European States in space research and technology and their space applications with a view to their being used for scientific purposes and for space applications systems." Such an approach has kept ESA focused on certain essentials and helped it avoid having to run an operational system.[21] When the Ariane launcher had become operational by 1982, for example, a private company called Arianespace, which had a special relationship with ESA, took on the responsibility of manufacturing, financing, marketing, and launching the Ariane vehicles.

Clearly, the Europeans had achieved their goals of launch independence. In its first four years of commercial operation, Ariane launched 12 satellites into orbit. NASA launched 30 in the same period, 9 aboard the Shuttle and the rest atop Delta and Atlas-Centaur rockets, which NASA sought to phase out at the time. Commercial competition in space transportation had become a reality—one accompanied by charges of unfair economic practices concerning subsidies leveled on both sides of the Atlantic. By the time of *Challenger* in 1986, the Shuttle and Ariane were virtually head-to-head in competition, with 44 launch contracts signed by Arianespace and the same number by the Shuttle. The Europeans and the Americans were having to learn to cooperate and compete simultaneously.

The nature of international cooperation changed during this period. Open-ended projects became more prevalent, where operations beyond data gathering were projected for long periods of time, necessitating larger, more complex infrastructures and commensurably higher operating costs. Basically, the scale and magnitude of operations changed dramatically, as exemplified in the Space Station and Hubble Space Telescope (HST) projects. NASA's bureaucracy had increased following the Apollo 204 fire, and with the addition of large, highly expensive operations of an extended nature, government and bureaucratic involvement intensified. In this way, the U.S. government became a more active participant rather than a facilitator, which had often been the case during the first period (1958-1973). However, during this latter period of U.S.-European cooperation, the balance also changed, with ESA becoming, for the first time, the lead partner with NASA, rather than European national space agencies, as had been the norm in the past. In this case, ESA was the lead partner with the United States and the former Soviet Union in the planetary sciences mission Giotto.

During Space Station negotiations, issues of management and jurisdiction were among the most difficult to agree upon. Politically, the U.S. Department of Defense (DOD) decision to insist in the midst of the negotiations

[21] Shuttle operations are now run by a private company, USA Consortium.

on inclusion of Space Station use for undefined "national security purposes" as part of the NASA negotiating proposal muddied the waters with international partners for some time. At one point, the negotiations even came perilously close to breaking down.[22]

In contrast, negotiations in the classic space sciences and Earth sciences, although occasionally tense and difficult, usually do not reach such dramatic levels. This is because they are more focused on common science objectives, whereas the Space Station involves a higher level of national commitment to a variety of nonscience goals.

The elements in the third period (see Box 2.3) that prompted the dual track of cooperation and competition were the technological maturing of the European space program and the institutional evolution of NASA. In the midst of this evolution, another arose: the end of the Cold War. This development in the global political environment changed the context of cooperation and competition enough to warrant (and indeed demand) that new parameters for future endeavors be outlined.

The Post–Cold War Years

Space and in particular space science are the province of the entire world. Progress in this realm can be demonstrated by the increasing number of countries and international entities involved in space activities during the past two decades. For example, the Inter-Agency Consultative Group (IACG) for space science continued after comet Halley receded and has focused on coordinating the armada of spacecraft involved in the International Solar-Terrestrial Physics (ISTP) program. In addition, the Space Agency Forum (SAF) has provided a forum where representatives of some 35 countries, agencies, and institutes engaged or entering into the space domain can meet annually for informal and timely exchange of information.

The U.S. Perspective

Since the end of the Cold War in early 1992, a number of important new factors (or old factors with new emphases) have come into play that have significantly affected U.S.-European cooperation in the space sciences:

- Opportunities for enhancing cooperation with the new republics of the former Soviet Union, particularly Russia, that simply did not exist before in the old, politically charged environment.
- Increasing emphasis in the United States on government-wide deficit and cost reduction, strongly supported across the political spectrum, which resulted in severe prospective budget reductions for NASA. This prospect has forced NASA to reorganize, moving many functions from NASA Headquarters to the field centers; downsizing its civil service and contractor work force; and moving to a "smaller, faster, cheaper" mode of operation that emphasizes smaller spacecraft that are developed more rapidly and feature new technologies. In addition, NASA's programs have been expected to be more relevant to national goals and priorities—for example, in foreign policy, putting a priority on cooperation with Russia and, in economics, emphasizing the development of technology with market potential to enhance American competitiveness.
- Placing important emphasis on small, rapid-turnaround, short-term missions such as those in the Discovery and Earth System Science Pathfinder programs,[23] within the context of long-range space science planning.

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[22] Johnson-Freese, J., "Space Station Negotiations: The New Considerations of Cooperation," *Changing Patterns of International Cooperation in Space,* pp. 83-91; Wilford, J.N., "Pentagon Wants Space Station for Missile Study," *New York Times*, December 29, 1986, p. A1; NASA Advisory Council, Task Force on International Relations in Space, *International Space Policy for the 1990s and Beyond*, NASA, Washington, D.C., October 12, 1987, p. 30.

[23] The Discovery Program is one of NASA's "smaller, faster, cheaper" initiatives for space science missions. Discovery missions use teams from industry, small businesses, and universities to develop small missions for less than $200 million (FY 1997 dollars). The Earth System Science Pathfinder (ESSP) program supports the development of small to medium-size, low-cost flight missions designed for Earth science investigations.

BOX 2.3 U.S.-European Cooperation: 1983-1992

Space Sciences

In the space science area, this third period began with a controversial question of principle between ESA and NASA. Although Announcements of Opportunity (AOs) for scientific experiments on NASA missions had been traditionally open to anyone of any nationality, ESA restricted its AOs for noncooperative missions to European scientists, in line with its charter. American scientists objected and requested reciprocity of access on ESA missions. Some scientists thought that certain European experiments were being chosen over U.S. experiments for NASA missions because they were provided free to NASA, as opposed to NASA's having to pay the costs of the U.S. experiments.

Although, strictly speaking, ESA could not be called on to reciprocate a policy that had been implemented by and large through bilateral agreements between NASA and individual member states, the ESA policy was changed by mutual consent in 1983. This was done after a spirited discussion within an ad hoc U.S.-European working group in which ESA acknowledged the ill will that this policy was causing. The first European proposal opened to non-ESA participants was the Infrared Space Observatory (ISO). Apparently NASA did not encourage American participation because ISO was considered a competitor of the proposed U.S. Space Infrared Telescope Facility.[1]

The ESA program in this period continued to show a prevalence of purely European projects, but the two major cooperative projects (HST and Ulysses) came of age. The bilateral cooperative missions launched in this period included AMPTE (United States-Germany-Great Britain), Galileo (United States-Germany), the Roentgen Satellite (Germany-United States-Great Britain), ASTROSPAS (United States-Germany), and the Gamma-Ray Observatory (GRO) (United States-Germany).

To strengthen and firmly establish the common European program, ESA made two fundamental moves in this period that also opened up new avenues to international cooperation: establishment and approval of the 20-year long-term plan, Horizon 2000, and creation of the Inter-Agency Consultative Group (IACG) for space science.

Horizon 2000, with its mix of "cornerstones" and smaller projects, reflects the distribution of interests and wishes of European scientists in different scientific disciplines. The plan won approval and increased funding from the political and financial authorities of ESA member states. It soon became a reference base for long-term planning and coordination among agencies worldwide and made possible the advanced coordination of major facilities.

The IACG was conceived in 1981 by science leaders at ESA to coordinate the scientific investigation of comet Halley. The spacecraft in the armada confronting the comet were the two from Japan (Sakigake and Suisei); the two Venus-Halley (VEGA) from the Soviet Union, which included a U.S. comet-dust experiment funded by NASA; and ESA's Giotto. The IACG successfully coordinated these projects and integrated the individual objectives in an overall strategy that was to the best advantage of scientific discovery. The IACG broke new ground and brought international cooperation and coordination to the planetary science level. It proved that this could be done to the benefit of all participants. The IACG concept succeeded because its goals were precisely determined, the interfaces and responsibilities clearly identified, the process informal, and the bureaucracy minimized.

Earth Sciences

In Earth observation, the 1983-1992 time frame was a turning point. After a period of discovering the potential of Earth observation from space, the development of new instruments opened two avenues for Earth observations other than the military one: practical applications with commercial outputs, and scientific programs. In all of these aspects, competition was clearly emerging. With the Landsat 4 launch in 1982, a new sensor, the Thematic Mapper (TM), was introduced. TM was a significant improvement over the Multispectral Scanner (MSS), providing greater spatial resolution in the visible and near-infrared

[1] Bonnet, R., and Manno, V., *International Cooperation in Space: The Example of the European Space Agency,* Harvard University Press, Cambridge, Mass., 1994, pp. 80-81.

regions (30 m versus 80 m) and three additional spectral bands. Système Pour l'Observation de la Terre (SPOT-1) was launched in 1986 by France, and it soon became clear that the mission was a success. Its high-resolution images (10 m) were the best the civilian space program had ever produced, and SPOT's capability of producing stereoimagery gave it added value for geological sciences and mapping applications. At the same time in the late 1980s, Landsat 5 was observing Earth globally at 30-m resolution.

Scientific investigations had been accomplished with Landsat as they had been with the meteorological satellites Nimbus and Tiros; however, the rationale for Landsat was applications. It is not surprising that the issue of commercialization and/or privatization of Earth observation efforts should arise.

The 1980s also saw a fundamental shift in the U.S. policy toward Earth remote sensing. Intense discussion in the United States early in the decade focused on the question of the roles of government and the private sector in Earth remote sensing. One view was that all civilian Earth remote sensing—meteorological, oceanic, and land—should be conducted by the private sector. An opposing view was that Earth observation is a proper function of government, since it is for a common good. The compromise focused on the land, and with passage of the Land Remote Sensing Commercialization Act of 1984, the National Oceanic and Atmospheric Administration (NOAA) was charged with "operating" the Landsat system while transferring the data to the private sector for distribution through sales. The Earth Observing Satellite Company (EOSAT) was awarded a contract to sell Landsat data for 10 years, and it was expected that two more satellites would be flown.

The compromise that excluded meteorological satellites was driven by many forces. To state it simply, the tradition of free and open access to weather data, the stronger scientific linkage with Nimbus and Tiros in comparison to Landsat, and the appearance of the French commercial land remote sensing satellite, SPOT, all drove the United States toward commercialization of Landsat.

The high cost of both Landsat and SPOT scenes meant that the volume of research conducted with these two satellites remained minimal, except for research conducted by the government. Both SPOT and Landsat were "commercial" enterprises; there was intense competition instead of cooperation, with SPOT-Image ahead of EOSAT in sales and profits. Landsat's inability to compete with SPOT was largely the result of DOD objections to making the highest-resolution technology available to commercial markets, apparently out of concern that it would facilitate targeting of missiles by potential enemies.

One of the early challenges that faced the Bush administration was the essential breakdown of basic U.S. policies relating to the Landsat system. Shortly after President Bush took office, NOAA announced it could not continue Landsat operations after March 31, 1989. At the last minute, the National Space Council provided emergency funds; however, Landsat's status would remain an issue until nearly the end of President Bush's term in office. President Bush signed the Land Remote Sensing Act of 1992, which repealed the 1984 act and transferred Landsat oversight from NOAA to joint NASA-DOD Landsat Program Management. The switch was made on the grounds that a broad national user group had become dependent on Landsat observations in addition to similar observations from meteorological satellites. Since then the program has become, once again, a NASA effort and formally part of its Earth Science Enterprise program.

Earth observation was back where it began, but by 1992, the stage for land remote sensing from space was becoming crowded. SPOT was continuing with some enhanced capabilities, Japan launched its first in a series of Earth Resources Satellites (JERS-1) in February 1992, and India launched its first two land-imaging satellites in March 1988 and August 1991.

The early 1990s began a period of great progress in Earth science. The concerns that fostered this progress were many, and most had come to the fore in the 1980s. There were environmental issues: concern about ozone, tropical deforestation, the changing chemistry of rainfall, and the rise of greenhouse gases and potential global climate change; there were experimental ones, such as the World Ocean Circulation Experiment (WOCE). There were international concerns: the endorsement in 1986 by the International Council of Scientific Unions (ICSU) of an International Geosphere-Biosphere Program, which would focus on human-induced changes in the planet's biogeochemical subsystem; and the World Climate Research Program, which would continue to concentrate on the other major component of the geosphere, the physical climate subsystem. Finally, there were the intellectual and conceptual issues that spoke to the

(continued)

BOX 2.3 (Continued)

idea of the Earth system itself as the object of study. To meet these scientific challenges, a number of spacecraft were planned, such as NASA's Earth Observing System (EOS) and ESA's Polar Orbit Earth Observation Mission (POEM) (later replaced with two satellites, Environmental Satellite [ENVISAT] and Meteorological Operational Satellite [METOP]), as well as a host of other missions. These activities dramatically shifted Earth remote sensing from one that was application centered to one that was science dominated.[2]

Microgravity Research and Life Sciences

In 1983 the first Spacelab flew, carrying experiments from NASA and ESA and ushering in the next period of U.S.-European space relationships. The European contribution to the Shuttle program, Spacelab, accommodated cooperative ventures in the life and microgravity sciences. Eventually, three types of Spacelab missions evolved. Several flights were strictly of U.S. composition and management. In three instances, a second type of mission was flown. Spacelab was contracted out to international partners, on the basis of a reduced cost for flying the mission in return for some involvement of U.S. scientists in the experiments. The three instances were the German D-1 mission, the German D-2 mission, and the Japanese SL-J mission. The manifest was prepared and managed by the contracting partner in all three cases. However, many of the scientific experiments were international in scope, involving principal investigators (PIs) and co-principal investigators from several different countries. The third type of mission, the International Microgravity Laboratory (IML), involved a mixture of experimental facilities and investigators from several countries but was managed by NASA. Each agency provided specific experimental facilities, paying for all the development costs of each facility provided. The individual agencies were also responsible for selecting their investigators to conduct experiments and were responsible for the costs of the specific investigations selected. Two missions of this type, IML-1 (1992) and IML-2 (1994), were planned and flown during this third period.

[2] Very productive U.S.-European collaborations were undertaken in field experiments designed to validate the extraction of information from raw data and to learn to assimilate Earth observation data in models: Hapex-Mobilhy in France (André, J.C., et al., "HAPEX-MOBILHY: First Results from the Special Observing Period," *Ann. Geophys.* 6[5]:477-492, 1988) and FIFE in the United States (Sellers, P.J., and Hall, F.G., "FIFE 1992: Results, Scientific Gains and Future Research Directions," *J. Geophys. Res.* 97(D-17):19091-19101, 1992; Sellers, P.J., and Hall, F.G., eds., *FIFE Experiment Plan,* NASA Goddard Space Flight Center, Greenbelt, Md., 1987). These experiments were conducted under the umbrella of the International Satellite Land-Surface Climatology Project (ISLSCP) (Rasool, S.I., and Bolle, H.J., "ISLSCP—International Satellite Land-Surface Climatology Project," *Bull. Am. Met. Soc.* 65:2, 134-144, 1984; Becker, F., Bolle, H.J., and Rowntree, P.R., *The International Satellite Land-Surface Climatology Project,* United Nations Environmental Programme, ISLSCP Secretariat, Free University of Berlin, Berlin, 1988). This change was fundamental and at the heart of important issues in the ongoing and evolving Earth remote-sensing dance of NASA and its many European partners.

- Emphasizing the convergence of civil and military research, hardware, and systems to maximize resources, with space considered a particularly ripe area.
- Privatizing many of NASA's operational functions, such as the Space Shuttle.
- Declassifying U.S. reconnaissance satellite data from 1960 to 1972, as well as declassifying the fact that these data were used for mapping, charting, and geodesy, in addition to their intelligence applications.

Emphasizing these factors means that the current era—1992 to the present—is distinctly different from previous ones. Acknowledging this fact is critical to planning future international cooperative efforts, and such acknowledgment is well under way. In assessing the external environment in its February 1996 strategic plan, NASA succinctly states the situation: "Over the past few years, the environment in which NASA operates has changed significantly. The Cold War has ended, but we find ourselves in the midst of vigorous global economic competition. There are also increased demands on Federal Resources. . . . With increased emphasis on pressing domestic needs, we will be required to ensure the relevance of our programs to national technological priorities and to other domestic goals in areas such as the environment, health, education, aviation and fundamental science."[24]

The period of FY 1992 through FY 1994 was one of transition, in which earlier expectations of growth that formed the basis for program planning were not realized. The consequences were dramatic: Approved programs were canceled or drastically restructured, supporting programs had losses, and plans for new missions went unfulfilled. The situation is now becoming even more drastic. Space science budgets are expected to be under severe stress through 2001, if not longer.[25]

In recognition of these fiscal parameters, program adjustments have been made in the Earth and space sciences. Programs such as Cassini, the Advanced X-ray Astronomy Facility (AXAF), the Far Ultraviolet Spectroscopy Explorer (FUSE), the Space Infrared Telescope Facility (SIRTF), and the EOS have been restructured. As previously mentioned, NASA instituted the Discovery program (among other new initiatives) to provide a framework for partnerships with an emphasis on other U.S. government agencies, industry, and academia. Although international cooperation is certainly not excluded, the short time lines involved make it more difficult to negotiate the parameters necessary for an international project and to respond in time to the NASA program approval process. This trend toward smaller, PI-type[26] missions is likely to continue to undercut the infrastructure of collaboration and cooperation that has developed over time. Since 1992, Earth science in general has been affected by the changing political and economic environment as many new national players have entered the field and commercial remote-sensing efforts have increased significantly. More broadly, commercial trends have clouded agreements on rules for the release or exchange of data and made them more complex. The increasing emphasis on commercial remote sensing may further exacerbate data rights for science as Congress considers a new Commercial Space Act that would require NASA to procure Earth science data from commercial companies.

Significant changes have occurred in the area of microgravity research and life sciences (MRLS) as well. Opportunities to make use of the Mir space station have opened up. This has both advantages and disadvantages. The advantages are that the Russians have had extensive experience in using Mir for the past 10 years and in conducting experiments in space, and the Mir station is already in space. A disadvantage is that Mir is unsuitable for much MRLS research because it does not have the microgravity environment, equipment, or capabilities for many modern experiments. The second major change is the advent of the International Space Station (ISS). Construction of the ISS not only preempts use of the Shuttles for science purposes, but continuing overruns in Space Station development costs may also negatively affect the development of the science to be performed there.[27] Therefore, projections for a strong MRLS science program in the United States into the next century are not promising.

The European Perspective

The sophistication achieved by space science, as well as the technological developments connected with it and the high costs and generally shrinking budgets for space activities, would suggest more than ever that long-term

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[24] National Aeronautics and Space Administration, *NASA Strategic Plan*, NASA, Washington, D.C., February 1996, p. 7.

[25] National Aeronautics and Space Administration, *Space Science for the 21st Century: The Space Science Enterprise Strategic Plan*, NASA, Washington, D.C., August 1995, p. 9.

[26] For the purposes of this report, a PI conceives of an investigation, is responsible for carrying it out, reports on the results, and is responsible for the scientific success of the investigation.

[27] Testimony by Mr. Daniel Goldin, Administrator of the National Aeronautics and Space Administration, given to the Science, Technology and Space Subcommittee of the Senate Commerce, Science and Transportation Committee hearing on the International Space Station, Washington, D.C., September 18, 1997.

plans be established well in advance. Long-term planning would allow high-level coordination at an early stage to avoid duplication of programs, encourage cooperation on specific projects, coordinate the planning of major facilities, increase data sharing, and thereby achieve an economy of scale and optimum scientific output. Despite increasing budget pressure, the ESA science program has responded to this changing environment with a follow-on of the Horizon 2000 plan, which extends to 2009 and defines broad objectives through 2016.

The perspective based on the Horizon 2000 plan has framed the European standing in the international space community. Although the ESA member nations could not meet the optimistic goals generated at the 1987 Ministerial Conference in The Hague, the long-term plans have still produced a series of missions that are at the forefront of their respective fields.

Toward the mid-1990s, the budget cuts of both the ESA science program and the national agencies (which are responsible for providing payloads and for scientific exploitation of the missions) threatened to erode the program so that its survival could now be in jeopardy. The Ministerial Conference in Toulouse (1995) had welcomed the extension of Horizon 2000 by Horizon 2000 Plus but had also reduced ESA's budget for the next 3 years by 3 percent annually.

In turn, European space scientists have struggled to maintain the long-term program. By enacting efficiency measures and by stretching the schedule of Horizons 2000 as much as possible, they have managed until now to maintain the integrity of the plans and with this, the solidarity within the research community. This solidarity has been important in establishing a Cluster backup mission, following the failure of Ariane 501 and the loss of the Cluster payload.

The ESA science program is adapting to external circumstances facing the agency. In light of NASA's new approach of heightening visibility though small and frequent missions, ESA has recently adapted the Horizon 2000 plan to include two types of missions to replace the old medium (M) class: The smart (S) missions are aimed at providing the technologies needed in the cornerstone missions; the flexy (F) mission (for half the price of the previous Ms) should maintain the program's flexibilities under severe budgetary conditions.

Other external circumstances affecting Europe's space programs include NASA's increased potential to make use for civil purposes of the large investments made in the United States military space sector. This has created a technological gap with Europe that could limit rather than expand cooperation among the space-faring countries of the world. This gap may also affect cooperative projects because the specific focus and time constraints presented in NASA's Announcements of Opportunity (AOs) for "smaller, faster, cheaper" missions make it difficult for Europeans to respond and participate.[28]

During this period, ESA has also restructured its Earth observation programs to accommodate science and applications. The scientific part is based on a series of Earth Explorer missions supported by ESA, and the applications part is based on Earth Watch missions, defined on a case-by-case basis and supported mainly by the user community. This process was approved by the ESA Ministerial Conference of Toulouse in 1995 and is now being implemented by ESA.

Cooperation in the Post–Cold War Era

With the end of the Cold War, certain national security concerns have abated. The convergence of civil and military research, hardware, and systems has in fact been encouraged in the United States to maximize resources, with space considered a particularly strong area. These efforts in research areas such as meteorology have opened up new possibilities for cooperative space work but have also complicated the process by adding new players with differing motivations.

The influence of politics as a motivation for cooperation has not ebbed; indeed, it has increased. However, the simplicity of the Golden Age of cooperation—with science as the focus; a hierarchy of players; near-term, closed-end projects; and minimal interfacing between partners—is gone. External factors will increasingly, shape the

[28] de Selding, P.B., "Budget Pressures Limit Joint Missions," *Space News*, December 2-8, 1996, p. 4.

major directions taken in space: "In the post-Cold War era, the foreign policy aspect of the civil space program will focus on a spirit of expanded cooperation with our traditional partners and the forging of new partnerships."[29] The opportunities are exciting, but the complexities inherent in working together should not be taken lightly. Many insights into easing the cooperative process may lie in an increased understanding and appreciation of the difference in structure, funding, and decision making on space issues between the United States and Europe.

THE UNITED STATES AND EUROPE: STRUCTURE, FUNDING, DECISION MAKING

Cooperation obviously depends on many issues. Some of these issues will always be murky; however, others could be clarified if there were greater understanding of the decision-making process at NASA and ESA. Although NASA, European agencies (ESA, ESRO), and European national bilateral agreements have existed for some 35 years, understanding of the prioritization, decision-making, and funding processes of the governments and agencies involved has sometimes been acquired through a painful learning process. The guidelines and legal constructs devised for international agreements, although generally familiar, do not always educate partners on the idiosyncrasies of cooperative projects.

U.S. Government System and Structure

One aspect of NASA's decision-making process involves seeking advice and identifying scientific goals. Internal and external bodies establish the direction for scientific disciplines, and based on these inputs, planning and prioritization follow. Scientific questions and goals are translated into defined mission concepts and research programs. Depending on the discipline, the link between scientific goals and mission platforms varies.

National Aeronautics and Space Agency

Advisory System. The NASA advisory process involves the National Research Council (NRC), which provides external independent counsel to the agency. The NRC Aeronautics and Space Engineering Board (ASEB) typically undertakes technology and design-related studies, whereas the Space Studies Board (SSB) advises on space science–related disciplines. Committees of leading scientists within these umbrella groups identify scientific goals and research priorities and focus mission evaluations and feedback to the agency on other scientific and programmatic issues (Figure 2.1).

Within NASA, each science office runs an interdisciplinary advisory system composed of experts from the external community as well as discipline-specific subcommittees. A top-level NASA Advisory Council includes the chairs from each program office advisory committee. Unlike the NRC, NASA's internal advisory groups provide advice on program planning and tactics (e.g., schedule, management, design, budget) in addition to science and research concerns.

Funding Process. Advice from internal and external sources may provide sound input for prioritizing goals and planning missions. However, these mechanisms cannot ultimately guarantee NASA's selection of or commitment to particular missions or research programs. Agency missions must compete for annual funding within the agency and against other government programs.

NASA's interaction with the U.S. budget cycle begins in April of year 1. At this point, NASA, like other federal agencies, receives general guidance from the Office of Management and Budget (OMB), a part of the Executive Office of the President. The agency asks the various NASA components for their proposals for the budget to be submitted by the president to Congress in January or early February of year 2 to cover federal spending from October 1 of year 2 to September 30 of year 3 (Figure 2.2). With NASA's comptroller acting as

[29] NASA, *NASA Strategic Plan,* 1996, p. 7.

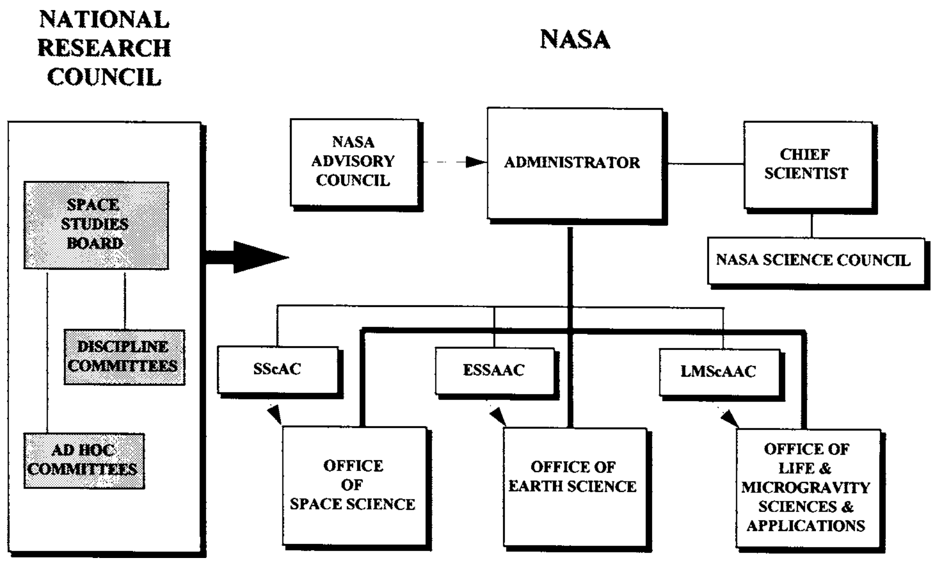

FIGURE 2.1 NRC-NASA advisory process.
NOTE: ESSAAC = Earth System Science and Applications Advisory Committee; LMScAAC = Life and Microgravity Sciences and Applications Advisory Committee; SScAC = Space Science Advisory Committee.
SOURCE: Adapted from Space Studies Board, National Research Council, *Managing the Space Sciences*, National Academy Press, Washington, D.C., 1995, p. 50.

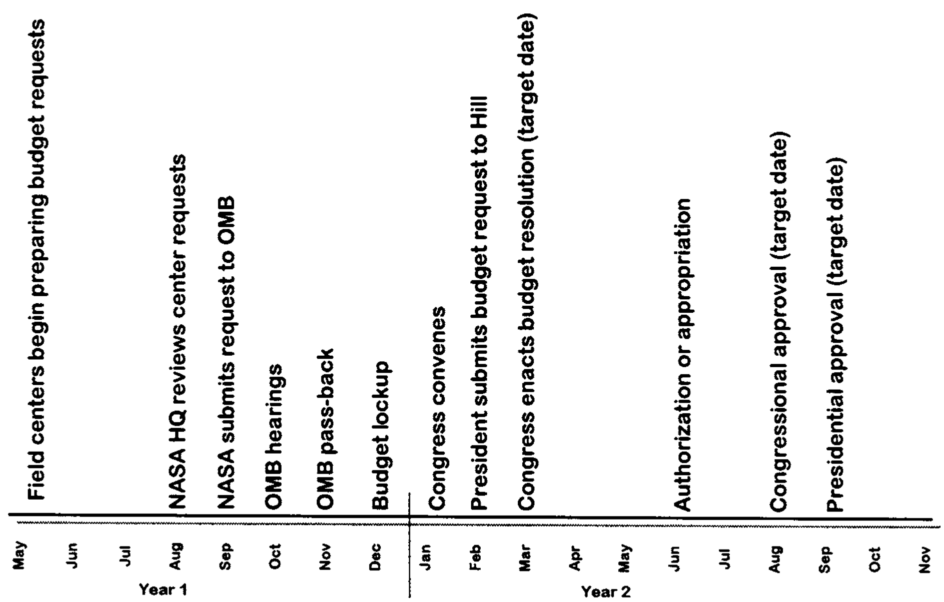

FIGURE 2.2 Congressional budget process.
SOURCES: NASA, Office of Legislative Affairs; Bill Green, former member, U.S. House of Representatives, Appropriations Subcommittee on Veterans Affairs, Housing and Urban Development, and Independent Agencies.

manager of the process, the budget requests from the several components of NASA are presented to the administrator and top management in midsummer of year 1. Typically the requests will total more than NASA's top management knows OMB will allow, and priorities are established in a series of meetings among the NASA administrator and top management. With the administrator ultimately making the final decisions at this stage, NASA proposes an agency budget to OMB at the end of August or beginning of September in year 1.

At this point, budget examiners at OMB specializing in NASA programs review its proposal. There is a good deal of back and forth between the examiners and NASA personnel until the final OMB decision at the end of November or beginning of December in year 1 about what is to be included in the president's budget. This decision is known as the "pass-back" to the agency.

The agency has the right to appeal to the president about OMB's pass-back. However, such appeals are not undertaken lightly. Most presidents do not relish having to settle disputes between their top appointees (e.g., the OMB director and the NASA administrator). Nor do agencies wish to earn the ill will of the OMB budget examiners who will be reviewing their future budget requests. However, such appeals do occur, and NASA has appealed OMB budget decisions.

The president sends the administration's budget request to Congress in January or early February of year 2; the budget request covers the period from October 1 of year 2 to September 30 of year 3. It also covers five "outyears," but such outyear recommendations are not binding on the administration or future Congresses.[30]

At this point the congressional process begins. The initial step is enactment of a budget resolution, which provides for the total amount to be spent, the total amount to be raised through taxes and other government revenues, and the resultant surplus or deficit. (There are also five-year outyear projections.) In addition, the resolution breaks down the spending into 19 functional categories; one of the categories covers NASA and some but not all of the other science spending. The budget resolution process is managed by the respective budget committees in the House and Senate, assisted by the Congressional Budget Office. The budget resolution is supposed to be passed by early spring in year 2 but is often delayed. The budget resolution must be agreed on by the House and Senate. It is not subject to a presidential veto because it is not a law but simply serves as a rule governing subsequent budget action in Congress.

Technically, the next step in the process would be an action by the authorizing committees in the House and Senate, which originate the legislation enacted by Congress to provide the statutory framework in which specific federal government activities occur and to authorize appropriations for particular activities up to an amount set forth in the authorizing legislation. Authorizing legislation, including the authorization of appropriations, may be for a single year or for more than 1 year.

The authorizing committees for NASA are the Science Committee (before 1995, the Science, Space, and Technology Committee) in the House and the Commerce, Science, and Transportation Committee in the Senate. The House Science Committee has generally been prompt in producing an annual authorization bill for NASA. For example, it reported out the FY 1998 NASA authorization on April 16, 1997, and the bill was passed by the House on April 24, 1997.

However, the Senate committee more often than not does not produce an authorization bill, and the Senate therefore relies on the appropriations process to deal with policy issues. Of course, House action does provide a "sense of the House" to its Appropriations Committee and subsequently to NASA. However, House procedure can permit a specific appropriation to be considered without authorization. In the Senate, the same result can be obtained by agreement among senators.

Though there is typically a good bit of debate about how spending is to be divided among the 19 functional categories, this portion of the budget resolution is not binding. The House and Senate Appropriations Committees are bound by the budget resolution's limit on total appropriated spending, but they are free to allocate this sum among their 13 subcommittees as they wish.[31] Moreover, the appropriations subcommittee jurisdictions are not

[30] This is true except insofar as Congress adopts changes in entitlement programs (programs, such as Social Security, which do not require appropriations because their statutory authorizations say that anyone who meets certain requirements gets paid automatically).

[31] Sec. 602, Budget and Impoundment Control Act of 1974, as amended.

congruent with the 19 budget resolution functional categories. NASA's appropriations are initiated by the Veterans Affairs (VA), Housing and Urban Development (HUD), and Independent Agencies Appropriations subcommittees in the House and Senate, whose jurisdiction extends, although not exclusively, across almost half of the 19 budget categories: Subcommittees are free to allocate the funds among the agencies within their jurisdiction as they wish (subject, of course, to the subsequent legislative process). Each VA-HUD-Independent Agencies Appropriations Subcommittee, with rare exceptions, produces a single bill that includes its proposed appropriations for NASA and the other agencies in its jurisdiction. These other agencies include the Department of Veterans Affairs, the Department of Housing and Urban Development, the Environmental Protection Agency, the National Science Foundation, the Federal Emergency Management Agency, and some dozen smaller agencies such as the Consumer Products Safety Commission.

After the respective House and Senate subcommittees complete their bills, they are passed on by the full Appropriations Committees and then by the House and Senate, respectively. Differences between the House and Senate are reconciled in a conference between the two subcommittees. What is produced must either be agreeable to the president, who can veto it, or able to command a two-thirds vote in both houses to override the veto.[32]

Not infrequently, Congress and the president are unable to agree on the appropriations bills by the October 1 start of the U.S. fiscal year. In this case, a Continuing Resolution is generally agreed to by Congress and the president (often after a certain amount of rancor) that provides for continuation of programs, usually at the lowest level contemplated by the House, the Senate, or the president, until a full-year appropriation can be agreed on.

Obviously large-scale NASA projects involve longer time frames than the annual budget process. Proposals for long-term projects must be evaluated, costed out, and compared with competing projects before they even show up as a line item in a NASA budget. Time scales here involve the development of novel equipment, planetary orbits, solar activity cycles, and so forth. NASA gets a substantial research and program management appropriation ($2,052.8 million in FY 1996) to cover its overhead and this preliminary work.

Typically such a large, long-term project has an initial "wedge," a midprogram "bulge" as the space vehicle is designed and built, and a declining "tail" dealing with transmission and receipt of data (although in the Office of Earth Science, data transmission, analysis, and provision of access to the larger Earth science community may be a major expense of the program). NASA tries cumulatively to schedule such programs so that they come and go within an envelope that represents the maximum NASA believes OMB will approve year by year. (NASA's share of the federal budget is a sore point within the agency; as Administrator Daniel Goldin noted in his testimony before the House VA-HUD-Independent Agencies Appropriations Subcommittee,[33] NASA has dropped from 4.5 percent of the federal budget in the Apollo years to 0.9 percent today.) Only when a proposed large program gets to the point in the queue at which NASA is ready to give it the go does it move from the research and development line to become its own line item in the budget.

A typical appropriation must be obligated during the fiscal year for which it was enacted or funding lapses. Thus, enactment of the initial appropriation is not a guarantee that future funding will be provided. Even after an appropriation is enacted, its spending can be deferred or rescinded. Deferral (postponement of spending until a later fiscal year) can be accomplished by the president, subject to congressional override; rescission (cancellation of an appropriation) requires that Congress approve the presidential proposal.

It should be understood that nothing in the current process prevents multiyear commitments. Congress can and does from time to time provide for such commitments. Even these can be canceled, as by rescission; but where there has been a contract with a third party (e.g., to procure a launch vehicle), its cancellation "for the convenience of the government" will be more expensive than cancellation of contracts that are by their terms subject to annual appropriation. The Clinton administration in its FY 1997 budget proposals sought to extend the multiyear commitment practice by requesting "full upfront funding" for projects in a number of agencies. In the case of

[32] Congress has by statute purported to give the president a line-item veto to appropriation bills. The matter, however, awaits an ultimate Supreme Court decision as to its constitutionality.

[33] Testimony of Mr. Daniel Goldin, Administrator of the National Aeronautics and Space Administration, given to the House Appropriations Subcommittee on Veterans Affairs, Housing and Urban Development, and Independent Agencies, April 25, 1996.

NASA, these projects included $342 million for the New Millennium Program ("a coordinated NASA/commercial partnership incorporating next generation technologies such as lightweight, low-cost instruments which improve performance and decrease mission costs in the future") and $558 million for the Tracking and Data Relay Satellite replenishment.[34]

Cost overruns have been a major issue with NASA. In his April 25, 1996, testimony to the House VA-HUD-Independent Agencies Appropriations Subcommittee, Administrator Goldin noted that "the GAO [General Accounting Office] conducted a survey a few years ago which showed NASA programs averaging 77 percent cost growth from their initial estimates." Goldin did not state any disagreement with the GAO findings (though he did go on to say, "Today, we are underrunning our program cost estimates from last year").[35] It can be argued that the annual appropriations process drives up costs, and this presumably is the reason for the administration's multiyear funding requests. However, the annual appropriations process was well known to NASA when it submitted its budget estimates and should have been allowed for in these estimates. It should also be noted that the percentage of cost overruns generally exceeded the 20 to 40 percent limits that let nations terminate participation in (20 percent) or generally result in cancellation of (40 percent) ESA projects.[36] Better cost estimates of projects in which NASA has the lead role will have to be a significant part of U.S.-European cooperation in space.

European Systems and Structures

In the space domain as well as any other, Europe cannot be visualized as a homogeneous entity. ESA is the only research and development space agency *of* Europe but not the only one *in* Europe. National space organizations coexist with ESA and interact with it in different ways.

Figure 2.3 illustrates the diversity of national organizations that contribute to funding ESA; European representatives determine the policy of the agency through participation in various decision-making bodies. This figure does not (and could not) represent the numerous bilateral agreements of varying time frames established among scientific institutions or national agencies.

The ESA Convention stipulates that national programs should be progressively integrated in the ESA. However, this goal has been difficult to achieve and remains, if at all desirable, a distant aim. In the present circumstances and more realistically, the goal is to achieve coordination among ESA and national programs, with ESA undertaking major missions of a scale larger than a single country could manage. In the space science area, effective coordination has become reality through ESA's long-term Horizon 2000 plan. This plan had a considerable impact on the development of space science in Europe and contributed to improved cooperation with European countries. Horizon 2000 has become the reference for national planning of space missions. A further tool to expand coordination is the biennial "Capri meetings," at which representatives present national initiatives to the other ESA countries and expand on possibilities for cooperation.

In space science the key players are, naturally, scientists. A 1992 estimate indicates that about 2,000 western European scientists are directly involved in space activities. The European Space Science Committee (ESSC) of the European Science Foundation (ESF), the coauthor of this report, performs the important role of synthesizing, promoting, and coordinating advice on European space science and policy from the space science community in Europe. In the general space area, interacting with ESA and with national organizations are a host of other institutions that, as in the United States, play a significant and sometimes, powerful role in European space policy. These are primarily the industrial complexes (particularly, the prime contractors), intergovernmental operational organizations such as the European Telecommunications Satellite Organization (EUTELSAT), European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), and private firms such as Arianespace and SPOT Image. Furthermore, the European Union (EU) through its three organs—Parliament, the Commission, and the Council—is playing a more active role in space affairs and in the establishment of space

[34] See Goldin testimony, April 25, 1996.
[35] Specific program-by-program cost overrun data can be found at pages 115 and 116 of the subcommittee's FY 91 NASA hearings.
[36] See Goldin testimony, April 25, 1996, and the subcommittee's FY 1991 hearings.

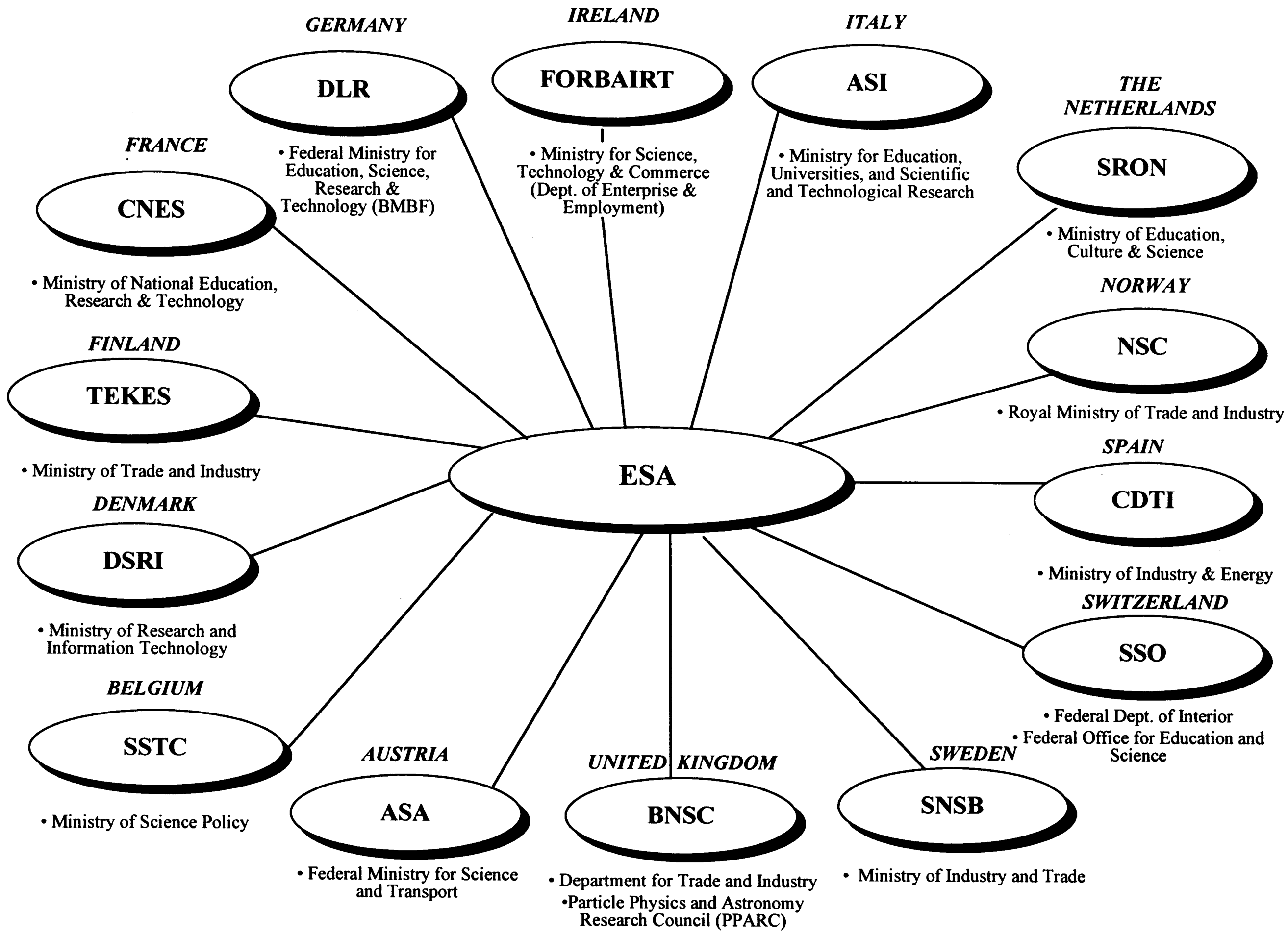

FIGURE 2.3 National organizations that contribute to funding ESA.
SOURCE: European Space Agency; Bonnet, M., and Manno, V., *International Cooperation in Space,* p. 67.

policy. The industrial policy rules of the EU, which aim at full liberalization of the market, may ultimately have a significant effect on the space industrial landscape of Europe.

The European Countries

Surveying the 14 or more national space agencies in western Europe to describe their individual selection and funding procedures would be complicated. Those agencies of the former Soviet bloc countries would now have to be added. Furthermore, agency procedures and priorities are in continuous flux to accommodate the shifting political, scientific, and industrial scenario in Europe. Compared with international organizations such as ESA, where conflicting national interests may lead to impasses and rigidity in decisions and management, the national space agencies have a higher degree of flexibility because of their ability to make autonomous decisions. However, despite its rigidity, the ESA mandatory scientific program has had an important impact on the scientific space policy of ESA member states and forced them to unite in their efforts toward joint goals. In addition to participation in ESA cooperative programs, most if not all of the European space-faring countries have bilateral programs, particularly but not exclusively with NASA and of course among themselves.

European countries have different policies regarding the proportion of funds each allocates to national, bilateral, and multinational (e.g., ESA) programs. There is no guiding principle, and countries of different sizes can have comparable allocations to national and joint space programs. However, major criteria for allocations include whether or not a particular country has a national space organization and the fraction of gross national product (GNP) that it commits to space activities. Countries with large national space programs and organizations tend to be less dependent on ESA to achieve their goals but typically have a decisive influence on ESA's policy decisions. Other countries in Europe have opted to let ESA be their principal focus of space activities and tend to contribute strongly to the establishment and cohesiveness of a joint European space policy. These countries essentially consider ESA a substitute national entity and therefore use its advisory, administrative, and financial structures as vehicles through which to channel national funds to their own institutes and industries (e.g., the Scientific Experiment Development [PRODEX] Programme).[37]

The European Space Agency (ESA)

Within the European Space Agency, the scientific program concerns only space science; scientific research in Earth observation, microgravity, and life sciences, as well as Earth observation applications, has different structures and processes.

Space Science: The Mandatory Scientific Program. The scientific program is the core of ESA's mandatory activities (which also include technological research, future project studies, shared technical investment, information systems, and training programs). This is the program for which ESRO was established. The ESA Council, which is composed of representatives from each member state, refers matters related to the ESA scientific program to an official Science Programme Committee (SPC). The SPC maintains a privileged position within the ESA body because it is the only program committee under Council authority to be specifically identified in ESA's Convention.

Funding Process. The scientific program budget is based on the mandatory contributions of the member states. These contributions follow a key related to countries' respective GNPs. The two concepts—mandatory and GNP-related contributions—are central to the management practice governing the science program. From a procedural point of view, financing of the science program is determined through a 5-year level of resources, which the Council must approve unanimously and which is reviewed every 3 years. Annual budgets proposed by

[37] PRODEX (Programme de Développement d'Expériences Scientifiques) is an ESA optional program that provides administrative, financial, and technical support assistance to ESA members requiring management support for their ESA projects.

the SPC have to be consistent with the overall level of resources and must be approved every year by the Council by a two-thirds majority.

One characteristic of the scientific program by which ESA differs substantially from other agencies such as NASA is that payload elements selected through competition by the SPC to fly on an ESA spacecraft are financed nationally rather than from ESA's science budget, which funds spacecraft and such common facilities as the telescope optics or cryogenic systems. This has been ESRO and ESA policy over the years and has encouraged a high degree of involvement and initiative within scientific groups that could not take funding for granted. As far as the data are concerned, it is the task of ESA to ensure that all scientific results are published after prior use by the investigators responsible for payload elements.

Selection Procedures. The fundamental rule of ESRO, and subsequently ESA, has been that ESA exists to serve scientists and that its science policy must be driven by the scientific community, not vice versa. This principle has profound implications for relations between the scientific community and ESA and explains the determining influence that ESA's advisory structure has on the definition and evolution of the scientific program. Currently, the advisory bodies in space science are the Space Science Advisory Committee (SSAC) and its two related working groups, the Astronomy Working Group (AWG) and the Solar System Working Group (SSWG). They advise the director general and the director of the scientific program on all scientific matters, and their recommendations are independently reported to the SPC. Ad hoc working groups may also be appointed to advise on particular subjects. For example, in 1993, a special ad hoc working group in fundamental physics and general relativity was formed to advise ESA on selection of the Satellite to Test the Equivalence Principle (STEP) project. Another was the so-called survey committee, which formulated the long-term plan for space science (i.e., the Horizon 2000 program) on the basis of input contributed by the European scientific community.

Membership on the scientific advisory bodies is for 3 years, and the chairs of the AWG and SSWG are de jure members of the SSAC. One of the main tasks of these bodies is competitive selection of scientific projects that will best meet the scientific objectives of the long-term program, which was designed over a decade or so to satisfy different disciplines that compete for funding. The recommendations of the discipline working groups (AWG and SSWG), each of which usually selects one project out of two or three competitors, are presented to the SSAC, which covers the ensemble of space-oriented disciplines. The SSAC, on the basis of these recommendations and taking into consideration scientific, programmatic, and financial elements, makes the final choice among competing projects. The SSAC recommendation, although not legally binding, is usually accepted by the ESA executive and is included in its own proposal to the SPC. The SPC is the final decision-making body for the scientific program. It is important to emphasize that SSAC decisions are the result of a balancing act between scientific arguments and verification that the budget, financial plan, and schedule for project development are compatible. The SSAC and SPC establish a strong connection between the project and its allotted financial envelope, which is the multiyear total cost at completion (CAC) for a project. The CAC, an integral part of ESA's decision-making procedure, allows for multiyear planning. (NASA's funding procedure, in which financial considerations weigh heavily on project appropriations in the upcoming fiscal year, limits the certainty of long-term planning.)

The SSAC formed the core of the survey committee. The membership of the survey committee, in addition to the SSAC, included representatives from international organizations related to ESA's scientific disciplines: the European Science Foundation, Centre d'Études et de Recherches Nucléaires (CERN), the European Southern Observatory (ESO), and the International Astronomical Union (IAU). Additional scientific teams were added to encompass all the disciplines in solar system exploration, astronomy, and astrophysics. This same committee reexamined Horizon 2000 and its successors (the Horizon 2000 Plus programs) following the budget resulting from the ministerial conference held in 1995.

Figure 2.4 is a flow chart summarizing the planning and implementation of ESA's science program. At all stages in the implementation process, the ESA executive keeps the SPC informed of both the progress and the problems encountered. After the approval of Phase B, the technical and financial evolution of the approved project is reviewed at least three times each year, the SPC being entitled, but not obliged, to stop it if the budget overruns its approved CAC by more than 10 percent.

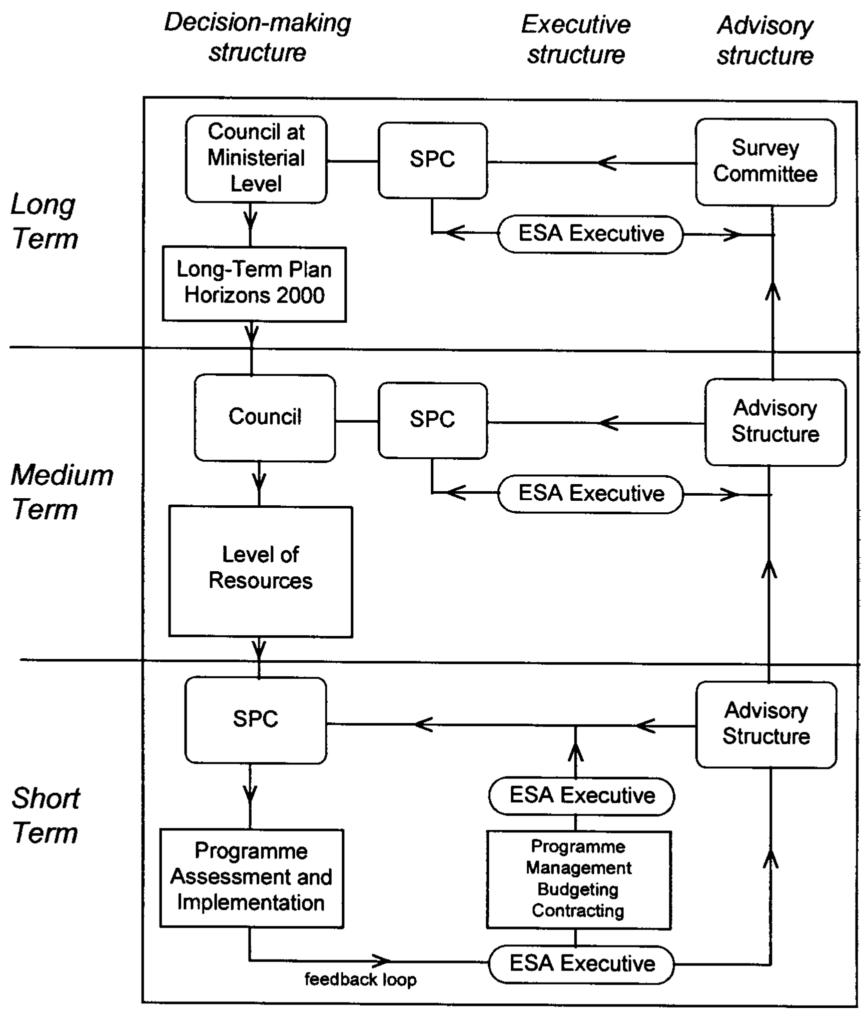

FIGURE 2.4 Flow chart for the planning and implementation of ESA's science (mandatory) program.

Earth Observation and Microgravity Research and Life Sciences: Optional Programs. An optional program means that each member state has the right to decide if it will participate or not and at what level (the industrial fair return [*juste retour*] rule is applied according to the financial participation). The basic layout is as follows, based on ESA's Convention, Article V 1.b, and Annex III, Articles I, II, and III:

- If a proposal for carrying out an optional program is made, it is discussed by the Council. If approved, an enabling resolution is established, authorizing the start of discussions by potential participants. Member states that do not intend to take part in the program have 3 months to formally say so.
- A declaration is drawn up by the potential participants to set out the undertaking of the program (i.e., phases and schedule, technical and budgetary aspects, level of contribution of each participating member state). The declaration is a legally binding document and is completed by a set of implementing rules. Both of these documents are established on the basis of a program proposal prepared by the ESA executive.

Optional programs are managed by ESA, which awards contracts to industry. The latest ESA Ministerial Council (March 1997) initiated a process, which will be implemented gradually until 1999, in which more flexibility is being fed into the system. Essentially, all participating member states are committed to continue in the program unless the cumulative cost overrun is greater than 20 percent of the initial financial envelope, or of the revised one in the case of price-level variations. This is established by regular reassessment of the program cost. If the program does exceed the 20 percent margin over budget, any participating member state may decide to withdraw from it. Participating states that nevertheless wish to continue with the program can consult among themselves and determine the arrangements for continuation. The philosophy of this policy is that the decision to approve a new program is difficult, but after a decision has been made, it is almost impossible for one country or a few countries to cancel it unless the program is much more expensive than planned (or unless a two-thirds majority of all participating member states decide to cancel it, providing this majority represents at least two-thirds of the contribution to the program).

The microgravity research program, an optional program that at ESA includes MRLS, has had a continuous history since its establishment in 1985 with the science programs EMIR 1 and 2 (ESA microgravity program) and the microgravity facility for Columbus. The program is based on an advisory structure, consisting of two working groups (Life Sciences Working Group and Physical Sciences Working Group), the Microgravity Advisory Committee, and the Microgravity Program Board. Selection of experiments is done by peer review. In the past few years, an interagency working group (NASA, National Space Development Agency [NASDA; Japan], Canadian Space Agency [CSA], ESA, CNES, DLR) was established for life sciences, with the aim of jointly issuing AOs for experiments and joint peer review for selection of experiments.

The Earth observation program, another optional program, was recently restructured and split between two directorates. All Earth observation programs currently under development or with corresponding platforms currently in orbit (i.e., European Remote Sensing Satellite [ERS], Environmental Satellite [ENVISAT], Meteorological Operational Satellite [METOP], METEOSAT Second Generation [MSG], and Earth Observation Preparatory Programme [EOPP]) are the responsibility of the Directorate of Application Programmes (D/APP) and include telecommunications. Future Earth observation (EO) missions and their strategy and implementation are being defined within the Directorate of Scientific Programmes (D/SCI). D/SCI has therefore integrated the existing Earth Sciences Division at the European Space Research and Technology Centre (ESTEC) with its scientific advisory committee, the Earth Science Advisory Committee (ESAC). This committee consists of scientists who represent the main disciplines and representatives of European scientific bodies (the European Science Foundation and the European Association of Remote Sensing Laboratories). In concert with the scientific community, the committee makes recommendations to ESA D/SCI regarding the missions to be launched and their prioritization. These recommendations are submitted for consideration by D/SCI to the Programme Board for Earth observation, which includes representatives of ESA member nations. Unlike the mandatory program, there is not yet a multiyear scientific program for Earth science in ESA, which makes the programmatic and the prioritization processes difficult. Such a multiyear program has been strongly recommended; an external scientific body[38] and ESA are now preparing the implementation of an envelope program for EO missions (including, in particular, necessary funding for the Earth Explorer program).[39] Unlike the mandatory program, instruments for most Earth observation programs are funded and developed by ESA. A few instruments are proposed by PIs in response to particular AOs. Instruments under ESA's aegis are prepared during Pre-Phase A and Phase A within the Earth Observation Preparatory Programme (EOPP) (which is again an optional program); EOPP's budget is also approved by the Programme Board for Earth Observation.

[38] European Space Science Committee, *Position Paper and Recommendations to the Ministerial Council of ESA Member States,* REP/95/7, European Science Foundation, Strasbourg, France, October 1995, pp. 13-14; European Space Science Committee, *Recommendations to the Council of the European Space Agency,* REP/96/3, European Space Science Committee, Strasbourg, France, 1996, p. 8.

[39] The strategy for future Earth observation missions at ESA has been determined. Science-related programs, which would include Earth Watch and the Earth Explorer program, will be developed by the Space Science Directorate. Applications-related programs like ENVISAT and METOP are incorporated into the Directorate of Applications. The Earth Explorer program is proposed to include research and development missions that address specific topics or techniques and will be funded by ESA. The Earth Watch program is envisioned to include thematic preoperational missions focusing on emerging applications; it would be funded by commercial financing.

In summary, the main characteristics of the ESA decision-making and funding processes are the following:

1. Recommendations and resolutions (in the ESA approval cycle);
2. Two types of programs: the ESA mandatory program (for space science, called the scientific program) and the ESA optional program(s) (à la carte for Earth science and for microgravity and life sciences);
3. The mandatory program assured of a 5-year level of resources approved by the ESA Council (with each country contributing an amount calculated as a function of its GNP); and
4. The optional program for Earth science, microgravity, and life sciences, in which participation on each project is optional, and the level of funding depends on national decisions and interest.

The following are ESA contributions to instruments and research:

- *Space science.* ESA provides spacecraft, general use facilities (e.g., telescopes, large cooling systems), launching, tracking, and operations and data processing through engineering calibration. National agencies provide the experiments, scientific data processing, and research funding.
- *Earth observation.* Ninety percent of the instrumentation is provided by ESA (this is not a rigid rule). The other 10 percent is provided nationally in response to specific AOs (e.g., Along-Track Scanning Radiometer and Precise Range and Range-rate Equipment [PRARE] on the ERS 1 and 2). Data processing for scientific purposes up to level 2 (geophysical products, when applicable) is provided by ESA. ESA does not fund research covered by member states on a national or multinational basis.
- *Microgravity.* Facilities are provided by ESA. Experiments to be performed at the facilities are provided on a national basis.

DIFFERENCES IN U.S. AND EUROPEAN VIEWS REGARDING COOPERATION ON SCIENCE PROJECTS

It is clear that there are major differences between the way Europe and the United States approve, fund, and conduct their space programs. Since these could be the subject of separate studies in themselves, the purpose of this section is to highlight major differences.

1. *Value of cooperation.* In the United States, the value of cooperation on science projects will depend on the foreign policy and market potential aspects, the ability to attract partner nations' resources to help carry out projects, the avoidance of competition, the added security in the annual congressional budget approval procedure, and the scientific and technological content.

In Europe, the value of such cooperation will be in the possibility of access to an otherwise unavailable facility; the scientific and technological content; the spreading of costs among all partners, leading to individual cost reductions; and, in the case of national bilateral projects, the foreign policy benefits.

2. *Space organizations and responsibilities.* NASA normally funds the development of spacecraft, scientific experiments, and research performed with the resulting data. With regard to science, ESA normally funds the spacecraft, but funding of scientific experiments and research is the responsibility of national (usually space) agencies. In other words, unlike NASA, ESA has no money for conducting research and data analysis, which is the responsibility of its member states. This raises the issue of how to reconcile scientific priorities in the scientific programs of member states with ESA's priorities. The situation is different for microgravity and Earth observation. Although both ESA and NASA are fundamentally R&D agencies, NASA has had a much stronger operational component because of its Space Shuttle operations. The tension between operations and R&D will increase in both NASA and ESA as operations on the International Space Station begin.

In Europe, ESA's charter emphasizes space research and technology for "exclusively peaceful purposes" and does not include participation in any military space programs. However, there is a move to interpret this charter more liberally and allow ESA involvement in "dual-use technologies" as long as they are for nonmilitary purposes (e.g., monitoring or security rather than weapons systems.) In the United States, although NASA is charged by the Space Act to direct and control nonmilitary aeronautical and space activities, the prohibition against participating in or supporting military programs is not as clear-cut or strong. However, “activities peculiar to or primarily associated with the development of weapons systems, military operations, or the defense of the United States” are clearly the purview of DOD. Furthermore, NASA has a strong aeronautics R&D component, which does not have a European multinational counterpart.[40]

3. *Funding procedures.* Funding procedures are the overriding and overarching differences that affect cooperation between ESA and NASA. This does not necessarily apply to bilateral Europe-NASA cases, because all nations have different procedures. In the United States, projects are generally a line item in the annual budget proposal and are thus exposed to the lingering threat of reductions or outright cancellation, particularly in the years of strictest budget discipline, typically before presidential elections. Congress, of course, has the power to approve multiyear appropriations, but this does not happen often.

At ESA, projects are approved for development at a certain cost at completion (CAC) and endowed with the corresponding multiyear funding. During the annual budget approval process, projects that are fulfilling financial predictions, within defined limits and accepted tolerances, are not threatened. (Unforeseen external political or financial events, such as the default of a partner, however, can call for revision of the entire program.)

4. *Legal documents.* The Memorandum of Understanding (MOU) has been, in the ESA space science area, the highest-level formal document used with NASA in cooperative projects. It establishes respective responsibilities in the hardware and operational phases, management tasks, consultation procedures, settlement of disputes, and schedule and time validity of the agreement. The MOU is signed for ESA, on unanimous approval of all member states, by the director general who acts within the framework of an international agreement ratified by all national parliaments and thus formally commits ESA to carrying out the MOU.

In the United States, the MOU is an executive agreement, a document whereby the separation of rights and duties of both partners is established. This falls short of the level of commitment to execution of the project that the ESA Council decision lends to the director general’s signature. The disparity between the U.S. and European approaches to MOUs, which was dramatically evidenced in the case of the International Solar Polar Mission (ISPM), is in fact quite natural since the MOU commits, at best, NASA but not the U.S. administration, let alone Congress. Higher-level agreements would thus be necessary to secure a level of commitment from the United States comparable to that given by ESA through the MOU.

5. *Decision-making processes.* In Europe, ESA’s space science projects are recommended by the Space Science Advisory Committee and selected by the SPC according to a long-term plan and within a funding envelope established by the council. Each part of the Earth observation and microgravity and life science programs has to be funded by the member states willing to contribute. This is decided within program boards for Earth observation and microgravity, respectively. In the United States, comparable planning involves the annual deliberations of NASA, its science advisory committees, the White House Office of Science and Technology Policy (OSTP), OMB, and Congress. The more extensive and more frequent involvement of the political and budget processes in Washington can result in more outside perturbations to NASA’s planning process than is the case with ESA in Europe.

6. *Involvement of military agencies.* In the United States, DOD is an important player in OSTP’s space policy deliberations. Through it (as well as directly with NASA and less formally through Congress), DOD can exert a strong influence on the U.S. civil space program. In Europe, no military agency has a comparable impact on ESA.

7. *Timing constraints on planning horizons.* There are positive and negative aspects to ESA’s and NASA’s planning processes, which are tightly linked to funding cycles. Although both NASA and ESA have long-term plans for their space science programs, NASA’s year-to-year budget appropriations can lessen the stability of its

[40] In its aeronautics research program, NASA clearly conducts research aimed at advancing military and civilian aviation.

long-term plans. NASA can often reprogram funds to cover budget changes in the smaller missions, giving it the flexibility for new initiatives and a "smaller, faster, cheaper" approach. The ESA system, although benefitting major missions that require long-term funding stability, is less flexible in short-term planning and less conducive to conducting smaller and medium-size missions. However, it should be noted that ESA was created to undertake satellite programs too expensive to be funded by any single country; this tends to inhibit it from undertaking small satellite programs.

8. *Industrial policy.* ESA has a policy oriented toward supporting European industry through the *juste retour* concept, whereas NASA has a much more flexible approach in this area. ESA's industrial policy has been reexamined by member states to allow more flexibility, still maintaining a *juste retour*.[41]

Commercial and/or competitive forces. In the area of Earth observation from space, where commercial interests are strongest, NASA's present priority is science first and commercial interests second. At ESA, with the currently proposed Earth Explorer program, which is primarily scientifically oriented, and the Earth Watch program, which is more oriented to applications and service, the situation will be different. This difference is reflected in the specific data policy defined for each of these programs: the data policy for Earth Explorer, which will be defined by ESA, and the policy for data acquired by satellites in the Earth Watch category, which will be defined by ESA partners that contribute to the missions. With regard to individual countries, there is only Système Pour l'Observation de la Terre (SPOT), an operational land remote-sensing program, designed and developed largely by France. Although SPOT data may be used for scientific purposes, they are sold commercially. In France, research laboratories are subsidized by the government to acquire these data.

[41] In March 1997, the ESA Council met in Paris to consider changes to the *juste retour* or industrial policy. The council consists of representatives from ESA's 14 member governments. Previously, ESA ensured that 96 percent of a member's contribution would be returned in industrial contracts to the member nation. The 1997 ministerial decisions will be implemented gradually until 1999.

3

Case Studies of U.S.-European Missions

This study seeks to help facilitate successful future international ventures in space. It is based primarily on the joint committee's evaluation of the cooperation and collaboration in space that has existed between the United States and Europe. The joint committee has tried to extract the crucial items that either facilitated or hampered each cooperative project. Among the joint ventures that have been selected for this study, some have been considered successes, others failures, or even a success by one partner and a failure by the other.

Because the disciplinary base may highlight different components of the issue of international cooperation, this chapter accounts for the particulars of each discipline—Earth science, space science with its subdisciplines (astrophysics, space physics, and planetary science), and microgravity research and life sciences—by examining a few selected missions from each area. Selection of these case studies was made so that a cross section of the approaches and experiences (both positive and negative) in the respective disciplines could be achieved. The rationale for this choice within each discipline is presented below (Table 3.1). Given the large variety of missions and types of cooperation, selection was also made to cover the greatest number of situations, as shown in Table 3.2.

In this chapter, the missions selected as case studies in each discipline are characterized briefly with emphasis on specific problems that arose from their international makeup. The findings by discipline follow the case studies; Chapter 4 presents the integrated findings and conclusions of the joint committee.

The following are among the questions that guide these considerations:

1. What were the scope and nature of the agreement? How did the agreement evolve, and how was it finalized? How long did it take to plan the mission?
2. How was the cooperation initiated (e.g., by scientist-to-scientist or agency-to-agency contact)? What was the role of each partner and agency? Were the motivations the same for all partners?
3. What were the expected benefits each partner offered?
4. What were the extent and practical mechanisms of cooperation? At what level, if any, did hardware integration of multinational components take place? How were communications maintained? Was the project structured to minimize friction between international partners?
5. What was the net impact of internationalization of the mission in terms of costs, schedule, and science output?
6. What external influences affected the mission during its life cycle? What were their effects? Were problems caused by different internal priorities or by external (e.g., political, financial) boundary conditions (such as budget cycles)?

TABLE 3.1 Missions Used as Case Studies in This Report, Selected by Discipline

Disciplines	NASA-ESA	NASA-European National Space Agencies
Astrophysics	HST, SOHO,[a] INTEGRAL	ROSAT
Planetary sciences	Cassini-Huygens, GMM	
Space physics	ISPM [Ulysses], ISEE	AMPTE
Earth sciences	EOS—Polar platforms	UARS, TOPEX-POSEIDON
Microgravity research and life sciences	IML-1, 2	IML-1, 2

TABLE 3.2 Missions Used as Case Studies in This Report, Selected by Type

Mission Type	NASA-ESA	NASA-European National Space Agencies
Observatory type, large facility shared	HST, INTEGRAL, IML-1, 2	IML-1, 2
Programs with several satellites or missions	GMM, ISPM [Ulysses], ISEE	AMPTE
Missions with few instruments		TOPEX-POSEIDON
Missions with large number of instruments	SOHO, INTEGRAL, Cassini-Huygens, EOS—Polar platforms	UARS
Initiated by principal investigator		AMPTE, ROSAT, TOPEX-POSEIDON

NOTE to Tables 3.1 and 3.2: AMPTE = Active Magnetospheric Particle Tracer Explorer; EOS = Earth Observing System; ESA = European Space Agency; GMM = Generic Mars Mission; HST = Hubble Space Telescope; IML = International Microgravity Laboratory; INTEGRAL = International Gamma-Ray Astrophysics Laboratory; ISEE = International Sun-Earth Explorer; ISPM = International Solar Polar Mission [renamed Ulysses]; NASA = National Aeronautics and Space Administration; ROSAT = Roentgen Satellite; SOHO = Solar and Heliospheric Observatory; TOPEX = (Ocean) Topography Experiment; UARS = Upper Atmosphere Research Satellite.

[a] SOHO is used by both astrophysicists and space physicists. Its mission addresses both disciplines. For the purposes of this study, SOHO was analyzed as an astrophysics mission.

7. Were there issues of competition versus cooperation? Did the desire to protect technological leadership create problems?
8. What benefits did the cooperation actually produce?
9. Which agreements succeeded and which did not, in both scientific and programmatic terms?

The questions are not formally asked and answered for each mission case study but serve instead as guideposts. In the end, the joint committee sought to know and present the lessons learned and how they can be applied in the future.

ASTROPHYSICS

The four missions selected—the Hubble Space Telescope (HST), the Roentgen Satellite (ROSAT), the Solar and Heliospheric Observatory (SOHO), and the International Gamma-Ray Astrophysics Laboratory (INTEGRAL)—span a wide range of involvement by the National Aeronautics and Space Administration (NASA) and by space agencies in Europe. They also involve a variety of subdisciplines, mission sizes, and degrees of complexity.

- *HST.* This major mission for astronomy, with a European Space Agency (ESA) share of 15 percent, has had very high visibility for both the astronomy and astrophysics community and the public at large. Particularly since it was repaired, the scientific productivity and impact of the Hubble have been enormous. As an example of international cooperation on such a high-visibility mission, HST has been quite successful. It may have suffered (in the United States at least) from not having been widely recognized as involving significant contributions and participation from outside NASA.
- *ROSAT.* This is an example of a mission based on a national program (Germany), rather than ESA, and that has produced a highly successful cooperation among Germany, NASA, and the United Kingdom (UK). The mission was greatly enhanced by the international cooperative effort, which provided both key instruments (the High Resolution Imager [HRI] and Wide Field [WF] Camera) and mission launch. This is a principal investigator (PI) based mission that illustrates agency-national and interpersonal collaboration.
- *SOHO.* The SOHO mission is currently providing the most powerful and complete view of the Sun ever obtained. It epitomizes international planning and execution, with more than a dozen separate instruments provided by laboratories across Europe and the United States. SOHO demonstrates that even the wide-ranging breadth of instrumentation desirable for a modern mission with a wide variety of capabilities can be executed by international agreements and planning. As a "cornerstone" mission of Horizon 2000, SOHO also represents a case of long-term planning and cooperation.
- *INTEGRAL.* As the next major gamma-ray astronomy mission planned for a 2001 launch, INTEGRAL represents a contrast in its international planning from the first three (operating) missions. The long planning process led by ESA was disrupted by significant reduction in NASA's contribution from, originally, the major share of one of the two primary instruments—the spectrometer—to only a token involvement. This can be partly traced to a lack of strong, broad community support in the United States, concerns about the priority of the proposed U.S. instrument, and the rapidly changing outlook for funding within NASA.

Hubble Space Telescope

Introduction

The Hubble Space Telescope has had the greatest impact of any observatory-type facility available in space. The two main reasons for placing a large optical telescope in orbit are to escape the degradation of images caused by atmospheric turbulence and to allow high-resolution imaging and spectral analysis in the ultraviolet (UV) range. Moreover, achieving significant gains over ground-based instruments requires a large collecting power and high-precision optics. These demands create a heavy, complex, and expensive satellite. HST's history is consequently long, complex, and expensive.

The HST is the result of international cooperation between NASA and ESA. NASA has led this effort and provided the spacecraft, the telescope, and four of the five original instruments as well as the ground segment and launch. ESA contributed one instrument, the solar panels and their mechanisms, and support for some scientific and technical staff at the Space Telescope Science Institute (STScI), which operates the HST from its facilities on the campus of Johns Hopkins University in Baltimore, Maryland. This is described in further detail below.

HST consists basically of a reflecting 2.4-m telescope that collects and focuses light on one or more scientific instruments. The current instrument package includes two direct-imaging cameras—the Wide Field and Planetary Camera Second Generation (WFPC2)[1] and the Faint Object Camera (FOC)—and the Near-Infrared Camera and Multi-Object Spectrometer (NICMOS) and the Space Telescope Imaging Spectrograph (STIS).[2] The optics reflect

[1]The original WFPC was replaced in the 1993 servicing mission by WFPC2, which is similar but includes a revised set of filters that have been improved for the far UV, a new type of charge-coupled device, and corrective optics for the spherical aberration in the primary mirror.

[2] NICMOS permits imaging in the wavelength range between 1000 and 2500 nm and spectroscopy between 1000 and 3000 nm using three grating spectrometers. Three cameras simultaneously observe different portions of the field of view. The detectors and part of the optics are cooled to 60 K by solid nitrogen, with an anticipated lifetime of 2 years. On the other hand, STIS is able to replace the performance of GHRS and FOS by using a 2,000 × 2,000 pixel multimode microchannel array detector providing 8,000 times the elements of its predecessors.

light adequately with wavelengths between about 115 and 3000 nm, from the UV to the near infrared (NI). Pointing stability is met by using three interferometric Fine Guidance Sensors (FGS) on the field of view's periphery, which are also operated as an additional scientific instrument.

The original instrument package included the WFPC, the FOC, the Faint Object Spectrometer (FOS), and the Goddard High Resolution Spectrograph (GHRS). As a result of discovering a manufacturing flaw in the primary mirror on the observatory, NASA conducted a servicing mission in December 1993 and installed the corrective optics package, Corrective Optics Space Telescope Axial Replacement (COSTAR). After COSTAR was installed, the blurred vision of the original HST was restored; this repair required removing the original high-speed photometer. In addition, the STIS (which replaced the FOS and the GHRS) was also installed and the WFPC was upgraded. The NICMOS was added during a second servicing mission in 1997.

Historical Background

The potential advantages of carrying out astronomical observations from space, beyond Earth's atmosphere, were first pointed out by the German rocket pioneer Hermann Oberth in 1923.[3] The original idea for HST evolved from the pivotal paper by Lyman Spitzer in 1946[4] in which he discussed the need for and many advantages of a large space telescope for optical and UV observations of the universe. The primary goals of such a mission were to achieve near-diffraction-limited imaging and spectroscopy in the UV optical (120-700 nm) range with a telescope aperture large enough to allow observation of faint objects.

More than a decade later, between 1962 and 1965, NASA sponsored several studies of a large orbiting telescope.[5] The concept began to take a specific form and dimension, and during the early 1970s, studies of a NASA mission concept for a 3-m Large Space Telescope (LST) were carried out.[6] These led to definitive studies between 1973 and 1976 establishing parameters for the basic mission. The LST study concept included four scientific instruments (camera, spectrograph, photometer, and astrometric camera) for spectrographic and photometric observations between 120 nm in the UV and 1,000 nm in the IR. The outline of the mission scenario anticipated a 1982 launch date.

The U.S. astronomy community rallied behind the space telescope as the highest-priority objective of the decadal study for astronomy for the 1970s, the Greenstein Report published by the National Academy of Sciences in 1972,[7] and reaffirmed its priority in the next decadal review, the Field Report, in 1982.[8] The actual selling of the project to a reluctant U.S. Congress (because of the cost) was accomplished due to the expressed consensus of this community and the pivotal leadership of a number of leading astronomers.

Cooperation

From the start, European astronomers were willing to join their American colleagues in this important effort. The issue of cooperation was first formally raised in 1973 when ESA's Astronomy Working Group (AWG) recommended that Europe consider and explore the possibility of participation in LST. ESA conducted long negotiations with NASA for this purpose. The selection was narrowed down to the FOC through a series of

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[3] Jakobsen, P., and Laurance, R.J., Oberth Paper, *ESA Bulletin* 58:91, 1989.

[4] Spitzer, L., *Astronomical Advantages of Extraterrestrial Observatory* (Project RAND Report), Douglas Aircraft Co., 1946.

[5] National Academy of Sciences, *A Review of Space Research* (Publ. No. 1079), NAS, Washington, D.C., 1962.

[6] In May 1975, NASA decided, for cost reasons, to reduce the size of the telescope primary mirror from 3 to 2.4 m, and the term "large" was dropped from the mission's title. The name Hubble was added by NASA in 1983, in honor of the American astronomer Edwin P. Hubble.

[7] Astronomy Survey Committee, National Research Council, *Astronomy and Astrophysics for the 1970s,* National Academy of Sciences, Washington, D.C., 1972.

[8] Astronomy and Astrophysics Survey Committee, National Research Council, *Astronomy and Astrophysics for the 1980s*, Washington, D.C., National Academy Press, 1982.

discussions within the AWG and with NASA.[9] The decision was prompted, in part, by the FOC requirement of a detector imaging system that could work in a so-called photon-counting mode to exploit the space telescope's potential to the fullest. At the time, Europe had a lead in this area, since University College London had developed the only photon-counting imaging system then in routine use for optical astronomy.

In June 1975, a NASA-ESA working group was charged with establishing common ground regarding the basis of eventual cooperation on the LST. This working group proposed that along with the FOC, a continuing European contribution to the telescope's operation and the provision of a major subsystem would be appropriate. This would allow ESA to secure a significant share of the observing time for European astronomers during the then planned 10 years of operations. It was proposed that ESA help to staff the Science Operations Facility, later renamed the Space Telescope Science Institute (STScI). Later, ESA was to set up its own Space Telescope–European Coordinating Facility (ST-ECF) at the European Southern Observatory (ESO) site in Garching, Germany. The major spacecraft subsystem to be provided by ESA was the solar arrays.

For ESA, the project's feasibility study, or Phase A, was completed, and subsequent discussions led ESA's Science Programme Committee (SPC) to accept a proposal presented in October 1976, subject to satisfactory negotiation of the Memorandum of Understanding (MOU) with the United States. The HST project thus evolved into a joint NASA-ESA mission. The U.S. Congress approved a "new start" for the project in the summer of 1977, and a formal MOU between NASA and ESA was signed on October 7, 1977. No less than 15 percent of the observing time available would be guaranteed to European astronomers in exchange for the solar panels; one of the main scientific instruments, the FOC; and 15 positions at the STScI.

The cooperation was formalized to include active ESA participation in mission planning and data analysis. At the time of the establishment of STScI at Johns Hopkins University and the appointment of its first director in July 1981, the links were well established. ESA personnel were already on-site at STScI, with ESA involvement ensured by representation on the Space Telescope Institute Council (STIC). Indeed, the previous chair of the STIC was from an ESA member state.

The original launch date of late 1983 was postponed several times until late 1986 because of funding and technical delays. Furthermore, the Space Shuttle *Challenger* accident in January 1986 caused an additional delay of more than 3 years.

HST was finally launched by the Shuttle mission STS-31 from Kennedy Space Center in April 1990. During the commissioning period, a flaw was noted in the manufacturing of the primary mirror. Despite this setback, a large number of astounding phenomena and objects were discovered using HST, even though its mirror was flawed. As is now well known, HST recovered its full imaging and spectroscopic capability as a result of a highly successful repair mission in December 1993. During this first servicing mission, the solar arrays were replaced with new ESA-provided systems; the original WFPC was replaced by a new, more effective WFPC2 (including its own corrective optics); and COSTAR was introduced as a focal plane "instrument" (instead of the original high-speed photometer) to correct the optical beam incident on FOS, GHRS, and FOC. ESA actively participated in the definition and testing of COSTAR. Since the servicing mission, HST has been regarded as an overwhelming success by both the public and the scientific user community and must be acknowledged as a superb example of interagency cooperation and planning.

From the beginning it was NASA's intent to open its Announcement of Opportunity (AO) to the entire scientific community. The MOU guaranteed 15 percent for Europeans, and this was considered a built-in check of *juste retour* (fair return). In reality, European astronomers currently obtain approximately 20 percent of the available observing time after selection through the peer review system. Observations selected in the seventh

[9] The FOC instrument is sensitive in the wavelength range from 115 to 650 nm and is capable of operating in two basic modes: direct imaging with different magnifications, and the so-called long-slit spectrographic mode. Whereas the WFPC provides a slightly undersampled image of a wide region of the sky, the FOC is designed to fully exploit the unique imaging capability of the HST and provide images of the highest possible resolution and limiting sensitivity, although the fields of view of the three nominal imaging modes are very small. Moreover, the WFPC operates best at longer wavelengths, while the FOC is most sensitive in the blue and UV regions. It will be replaced in the third servicing mission (1999) by the Advanced Camera for Surveys (ACS) being developed by Johns Hopkins University with NASA funds.

observing program (cycle 7) are being performed following the second maintenance and refurbishment mission (STS-82) in February 1997.[10]

Additional servicing missions to HST are planned for 1999 and 2002, and a series of studies are being carried out for the continuation of the mission beyond 2005, the nominal termination of the HST 15-year lifetime. The ESA-funded FOC will be replaced during the 1999 mission by the NASA-approved Advanced Camera for Surveys (ACS). Solar arrays will again be replaced, and HST will be reboosted to a higher orbit to compensate for the orbital decay expected during the next solar maximum cycle.

The planned replacement of solar arrays by NASA (rather than, as originally supplied, by ESA) in the 1999 servicing mission has raised some concerns about ESA's role or hardware share in the extended HST mission. ESA's SPC approved procurement of the Solar Array Drive Mechanism (SADM) for the 1999 servicing mission. Given that the FOC will also be removed from the space telescope, the European contribution to the mission will be significantly reduced. In 1995, a joint ESA-NASA working group was set up to identify a potential HST instrument for the 2002 servicing mission, which could be provided by ESA to NASA. Two potential instruments—three-dimensional imaging spectrographs—to be provided entirely by ESA, were identified at an early stage. However, this approach for a complete ESA instrument was abandoned following budget reductions in the aftermath of the ESA Ministerial Conference in October 1995 at Toulouse. In October 1996, NASA released an AO for the provision of advanced instruments to be installed at the time of the 2002 (probably final) servicing mission; a NASA instrument (Cosmic Origins Spectrograph) was selected. Despite funding problems to accommodate further contributions to the cooperative program, ESA was able to respond to the AO through a collaboration between U.S. and European institutes with a 50-50 participation in proposing the HSTJ instrument, which incorporates Superconducting Tunnel Junction (STJ) detectors.

In the meantime, both ESA and NASA have begun to consider extending the current MOU beyond 2001, the present date of expiration. HST operations are funded on the NASA side to 2005, and mission extension beyond this date is possible, although not yet decided. In this case, a final servicing mission might take place in 2005. ESA also plans to contribute to NASA efforts to develop a Next Generation Space Telescope (NGST). On June 27, 1996, the NASA associate administrator for space science met with the ESA science program director and invited ESA to participate in the study of the "origins" program, which includes, among several missions, the NGST and an infrared interferometer. Formal working-level contacts are now being established, and a task force on NGST has been formed within ESA.

Finally, it is useful to consider the scope of HST. The cost to ESA is accounted as 462 million accounting units (MAU) in 1994 European Community Units (ecus), the equivalent of $547.4 million in 1994 U.S. dollars. The total mission cost to NASA (in real dollars) from inception is $4 billion or more, certainly the most expensive astronomical mission ever carried out and among the most expensive single scientific facilities yet constructed.[11]

Summary

The cooperation on HST between U.S. and European astronomers has worked very well. The fact that NASA had a leading position in the mission was never disputed; however, some European scientists have complained that NASA did not present the mission as truly cooperative and international in its public outreach on both the mission and its results. In addition, it was clearly important to have a well-defined MOU established at early stages. Drafting these kinds of MOUs was found, nevertheless, to be a lengthy process that does not include mechanisms for easily modifying or extending the mission. Europe's significant contribution to the scientific payload also proved crucial, not only to the spacecraft but also to HST operations at the STScI. This cooperation at STScI in the

[10] Cycle 7 is the seventh selection of the observing program, solicited by competitive peer review (approximately 7:1 oversubscribed) on an approximately annual schedule.

[11] Bahcall, J.N., and Odell, C.R., "Scientific Research with the Space Telescope," SEE N80-22130 12-88, 1979, p. 5; Laurence, R.J., "The History of the Hubble Space Telescope and ESA's Involvement," *ESA Bulletin* 61:9-12, 1990; Smith, R.W., *The Space Telescope: A Study of NASA, Science, Technology, and Politics,* Cambridge University Press, Cambridge, England, 1989; Wilson, A., ed., *Interavia Space Directory*, International Space Programmes, 1994, p. 163.

United States and the links to ST-ECF in Germany have ensured that HST has been conducted highly visibly and successfully on both sides of the Atlantic.

Roentgen Satellite

Introduction

The Roentgen Satellite is an x-ray telescope mission to provide the first soft x-ray (0.2-2.5 keV) (1 keV = 10^3 electron volts) all-sky imaging survey, as well as an observatory for detailed study of individual sources. ROSAT mission goals were twofold: (1) Using the scan mode, a complete all-sky survey was to be carried out over 6 months with imaging telescopes to detect sources at x-ray and extreme-ultraviolet (XUV) energies, to measure their positions with an accuracy of less than 0.5 arc minute, and to obtain fluxes and broadband spectra. (2) In the pointing mode, the goal was to study selected sources in detail with respect to spatial extent, temporal variability, and spectral properties. Pointed observations with the High Resolution Imager (HRI) also were to allow more precise (~5- to 10-inch) positions and structures to be measured. ROSAT was launched in June 1990 and provided a higher-sensitivity and higher-resolution follow-up to the Einstein X-Ray Observatory operated by NASA from 1978 to 1981 (with European participation in its grating spectrometer). It will have provided the highest spatial resolution x-ray imaging capability to date until the planned launch of the Advanced X-Ray Astronomy Facility (AXAF) in late 1998**.** ROSAT is a German-U.S.-UK project.[12]

Historical Background

ROSAT resulted from a proposal made by the Max-Planck-Institut für Extraterrestrische Physik (MPE) to the Bundesministerium für Forschung und Technologie (BMFT) in 1975. This was one of three projects selected from 20 proposals for ''big projects'' across a wide range of natural sciences. The original version of the project entailed an all-sky x-ray survey to be carried out with a moderate angular resolution (roughly 1-inch) imaging telescope. Between 1977 and 1982, extensive studies were conducted by German space companies in the pre-Phase A and Phase A stages. Following the regulations of the ESA convention, BMFT offered cooperation on ROSAT to ESA member states in 1979. This resulted in three proposals, one of which was successful.

The University of Leicester (UK) led a proposal for a Wide Field XUV Camera (WFC) to be flown together with the X-Ray Telescope (XRT) to extend the spectral band pass to lower energies. A formal proposal for UK funding was made by the WFC Consortium to the Science and Engineering Research Council (SERC)[13] in August 1981. After discussions between the University of Leicester and MPE and negotiations between BMFT and SERC, the MOU between these two parties was signed in 1983.

U.S. involvement in ROSAT was first discussed at the Uhuru Memorial Symposium in December 1980 when a German scientist talked about ROSAT plans and outlined the possibilities of international cooperation. Individuals at the Harvard Smithsonian Astrophysical Observatory (SAO) and an x-ray astronomer at NASA's Goddard Space Flight Center (GSFC) became interested, and further discussions among scientists at GSFC, SAO, and MPE, and between BMFT and NASA, led to a MOU signed in 1982. NASA agreed to provide the HRI for the focal plane of the XRT, as well as the ROSAT launch with the Space Shuttle in 1987. The HRI was developed at SAO as an improved version of the detector, which had been originally developed for the Einstein Observatory.

The *Challenger* accident of January 1986 brought about a significant change in the ROSAT project. In December 1987 it was decided that ROSAT would be launched on an expendable launch vehicle (Delta II) in 1990 instead of on the Space Shuttle. This required late changes to the satellite hardware, which fortunately were

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[12] As an international project, ROSAT was conceived and executed on a nonexchange of funds basis. Because offers from UK industry did not fully comply with requirements set by the management of Deutsches Zentrum für Luft-und Raumfahrt-Projektträger (DLR-PT), a transfer of funds took place from the United Kingdom to Germany.

[13] In April 1994, U.K. research councils were reorganized and SERC's responsibilities were shared between the Natural Environment Research Council (NERC) and the Particle Physics and Astronomy Research Council (PPARC).

modest despite the advanced stage of the project. On NASA's side, the launch required a modified shroud of the Delta II to accommodate ROSAT. The launch finally took place on June 1, 1990, from Cape Canaveral.

Cooperation

The heart of the cooperative effort was science, instruments, and data. The instrument contributions by SAO, UL and British institutes, and MPE were conducted separately. The institutes and agencies (particularly MPE, DLR-PT, and DARA) provided program management and scientific oversight, with science planning led by MPE. Many partners and entities shared responsibilities for scientific analysis software for guest observers and guest observer support and for preparation of the Announcement of Opportunity. Moreover, the data management, sharing, and analysis were developed and conducted in a distributed fashion involving most of the partners.

Instruments and Associated Data Systems. The ROSAT payload consists of two telescopes: the XRT with the position-sensitive proportional counter (PSPC), and the HRI, which was mounted on a carousel in the focal plane behind the XRT mirror assembly[14] and the WFC.

Overall direction of the science project was carried out as a PI mission at MPE, whereas the ROSAT project as a whole was managed by DLR-PT until 1990 and by Deutsche Agentur für Raumfahrt Angelegenheiten (DARA) thereafter. The main satellite contractor in Germany was Dornier System, with Messerschmitt-Bölkow-Blohm as a subcontractor. The Carl Zeiss Company developed and built the x-ray mirror system.

The U.S. contributions to ROSAT were the HRI, mission launch on a Delta II, and significant analysis software. For the pointing phase of the mission, NASA has conducted the observing proposal solicitation for input to the International ROSAT Users Committee (IUC). U.S. participation in ROSAT was managed at GSFC, which supported scientific planning as well as data reduction and distribution to the U.S. astrophysics community. GSFC also developed and maintains the ROSAT data archive for NASA and coordinates solicitation and review of observing proposals submitted by the U.S. community. The ROSAT Science Data Center (RSDC) is operated at SAO, where the HRI detector, telescope aspect software, and HRI data analysis software were developed. SAO also monitors the condition as well as the calibration of the HRI in flight.

The WFC was designed and built by a consortium of British institutes led by the University of Leicester.[15] The ROSAT UK Data Centre (UKDC) is located at the Rutherford Appleton Laboratory, Oxfordshire, whereas the ROSAT UK Guest Observer Centre (UKGOC) is located at the University of Leicester. Between them, the UKDC and UKGOC act as a link between U.K. observers and MPE's ROSAT Data Centre. The UKDC processes all WFC data and distributes pointed x-ray data (received from MPE) and WFC data to U.K. guest observers. It also sends all German WFC GO data to the German XUV Data Centre (at the University of Tübingen). The UKGOC provides general user support for ROSAT to U.K. guest observers (GOs). Analysis of the WFC all-sky survey has been the responsibility of the ROSAT UK Survey Centre at Leicester. The all-sky survey database has since been archived at the Leicester Database and Archive Service.

ROSAT was launched on June 1, 1990. After the initial calibration period, ROSAT performed an all-sky survey in a continuous 6-month period using the PSPC in the focus of the x-ray telescope and in two XUV wave bands with the WFC. Following the all-sky survey, ROSAT has been used for pointed observations using the PSPC or HRI. All of the observing time in the pointed phase is made available to guest investigators through an international, competitive peer review.

[14] The XRT telescope and the PSPC were developed by MPE in Garching, Germany, in collaboration with Carl Zeiss Company; the HRI detectors were developed by SAO in the United States.

[15] In addition to Leicester, the other institutions in the United Kingdom that had a major role were the Rutherford Appleton Laboratory, Mullard Space Science Laboratory of University College London, the University of Birmingham, and the Imperial College of Science and Technology London.

The Investigator Program. There are no restrictions regarding the amount of ROSAT observing time guest investigators may have, the percentage of observing time spent on long versus short investigations, or the number of targets requested in GO proposals.[16] Proposals submitted to each of the three agencies (BMFT, NASA, and PPARC)[17] are evaluated independently by the respective national proposal evaluation committees. The available observing time is shared in the ratio 50:38:12 among NASA, BMFT, and PPARC. Each agency approves enough proposals to cover about 150 percent of its nominally available national observing time. All proposals approved by each agency are grouped into one of four categories: two-sevenths for programs with highest priority, two-sevenths for programs with medium priority, three-sevenths for programs with low priority, and those that are not approved.

The three participating agencies (BMFT, NASA, and PPARC) independently define their national proposal lists. The IUC's task is to combine the three national programs into the ROSAT observing program. This observing program should be devoid of unnecessary duplication among nationally defined observing programs; redundant proposals are removed so that the national observing programs are changed as little as possible. To select between competing proposals, the IUC uses the priority and observing time allocated by national selection committees. The IUC recommends a final ROSAT observing program to BMFT and reports back to the national committees about any changes to individual national observing programs. As a result, a nationally approved proposal may be rejected on the international level because of a competing proposal. BMFT approves the ROSAT observing program on the basis of IUC recommendations.[18]

Summary

On the whole, cooperation on ROSAT has worked very well. Many hundreds of guest investigators have used the telescope during more than 7 years of operation. When problems have occurred (e.g., failure of several gyros), they have been solved through joint efforts.

Excellent communication has been central to ROSAT's success. There were, of course, the usual project reviews to monitor progress during the hardware phase. Numerous project meetings dealt with specific questions as well. This ensured constant communication among the engineers, scientists, and managers. At a higher level, there were the national ROSAT committees (for Germany, the United States, and the United Kingdom) and the IUC (eight members). The national and international users committees met several times before launch, and after launch they met at each AO cycle (eight times thus far). In addition, data management, sharing, and analysis, which are done in a distributed but concerted fashion (MPE, GSFC, University of Leicester [UL] with RAL), have been optimal, resulting in an excellent data service for a wide community. There was ample lead time: the data analysis effort at MPE started 8 years before launch; in the United States, it began 4 years before launch and in the United Kingdom about 6 years before launch.

ROSAT has been a highly successful mission that has made fundamental discoveries and many important observations. It provided the United States (and the world) with the only high-resolution (a few arc seconds) x-ray imaging observatory since the demise of the Einstein Observatory (1981) and until AXAF (1998). As an example of international cooperation, it must be regarded as a great success.

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[16] Pointed observation data are subject to proprietary data rights for a period of 1 year after the data have been made available to the PI.

[17] With the reorganization of U.K. research councils in April 1994, PPARC took over SERC's responsibilities for funding ROSAT in the United Kingdom.

[18] The ROSAT observing time is significantly oversubscribed (by a factor of four to seven). The most important criterion for assessment by national evaluation committees is the scientific merit of the proposed research. However, the feasibility of the observations, as well as observational constraints that may overburden the ROSAT system, also figure in the selection.

Solar and Heliospheric Observatory

Introduction

The Solar and Heliospheric Observatory is the most comprehensive space mission ever devoted to the study of the Sun and the heliosphere. From the vantage point of a halo orbit around the first Lagrangian point, L1, SOHO's 12 scientific instruments observe and measure structures and processes that occur inside as well as outside the Sun and reach well beyond the Earth's orbit into the heliosphere. The two extremes of this data, the deep core and the outermost layers of the convection zone, are unobtainable except from space.

The SOHO mission involves international cooperation among ESA, European national authorities, and NASA. ESA took the lead in the cooperation between the two large space agencies by procuring the spacecraft (including integration of the 12 instruments and environmental testing of the satellite) from European industry. Instruments were built under the leadership of PIs,[19] nine of them funded by European national entities and three by NASA.[20]

EUV and UV imagers and spectrographs have yielded the first comprehensive view of the outer solar atmosphere and corona. For the first time, the temperature, density, and velocity evolution of the solar atmosphere can be observed from the photosphere out through the far corona. Observations are continuous. Although SOHO is a single mission, experiments on board SOHO can be divided, according to their area of research, into three main groups: helioseismology instruments, solar corona instruments, and solar-wind in situ instruments. The helioseismology instruments provide high-precision and high-accuracy measurements of solar oscillations. The solar corona instruments produce the data necessary to study dynamic phenomena in the upper solar atmosphere. The solar-wind in situ instruments measure the composition of the solar wind and energetic particles.

NASA supplied the SOHO launch vehicle (an Atlas-2AS) and provides ongoing mission operations including communications with the satellite via the Deep Space Network (DSN). Overall responsibility for the mission remains with ESA. After its launch on December 2, 1995, SOHO reached its location near Lagrangian point L1, 1.5×10^6 km from Earth and was injected into the halo orbit on February 14, 1996.

Historical Background

Although the SOHO mission is a cooperative effort between European agencies and NASA, its origins at the agency level were in Europe. However, because of the range of well-developed scientific cooperation between the space communities on both sides of the Atlantic, the scientific parenthood was clearly shared.

SOHO was proposed 13 years before its actual launch and, less than 3 years after being proposed, had become part of an ESA Horizon 2000 cornerstone. The foundations of SOHO were laid in earlier studies, namely those of GRIST (Grazing Incidence Solar Telescope) and DISCO (Dual Spectral Irradiance and Solar Constant Orbiter). It is the combined capabilities and objectives of both of these project proposals that constitutes the core of the SOHO mission.

The GRIST proposal and Phase A study foresaw a grazing-incidence telescope (feeding several focal-plane instruments) to be mounted on the Instrument Pointing System (IPS) and flown as part of a Spacelab payload. One of the merits of GRIST was that the wavelength range accessible through grazing-incidence optics is particularly powerful for spectroscopic diagnostics of the hot outer solar atmosphere. Spectroscopy in this domain had long been neglected on major solar satellites, partly because of experimental difficulties.

In July 1980 in response to an ESA call for mission proposals, a group of French and Belgian scientists proposed a mission, DISCO, dedicated to the study of spectral irradiance and the solar constant. This was considered an important, broad objective, in part because of the possible climatic effect of a long-term variation in

[19] For the purposes of this report, a PI conceives of an investigation, is responsible for carrying it out and reporting on the results, and is responsible for the scientific success of the mission investigation.

[20] The 12 international PI consortia involved 39 institutes from 15 countries: Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Japan, the Netherlands, Norway, Russia, Spain, Switzerland, United Kingdom, and the United States.

solar irradiance. At almost the same time, in the austral summer of 1979-1980, a group of French and American physicists observed the Sun continuously from Antarctica between December 31, 1979, and January 5, 1980. They succeeded in measuring global velocity oscillations of the Sun with an unprecedented signal-to-noise ratio. These historic observations led to the decision to include helioseismology velocity observations on board DISCO.

In addition, the potential for helioseismology of solar brightness oscillations, as evidenced by the high quality of the solar constant data obtained by the Solar Maximum Mission (SMM), offered a unique asset to that mission, which could for the first time attempt to detect the Sun's global oscillation modes and shed new light on the intriguing solar neutrino deficit issue. An instrument measuring brightness oscillations would therefore add a substantial helioseismology assessment capability to the radiance and irradiance instruments. Accordingly, DISCO's model payload was extended to contain a set of photometers and absolute radiometers to perform measurements of the total and spectral irradiance in selected bands and detect solar oscillations in visible light.

An assessment study for SOHO was approved by ESA in December 1982. To create a larger scientific base for an eventual project, the Solar System Working Group recommended that a particle payload segment be included in the model payload. During the initial study phase, it became clear that SOHO should be a multidisciplinary mission, which implied the following: (1) helioseismology should be added to the set of spectroscopic solar telescopes forming the original payload; (2) SOHO should be placed in a halo orbit around L1 in order to be compatible with the helioseismological objectives; and (3) the particles-and-fields instruments should be devoted to solar-wind composition measurements, the study of solar energetic particles, and the investigation of waves in the interplanetary medium.

Cooperation

The studies of DISCO and SOHO coincided with cancellation by NASA of its probe in the International Solar Polar Mission (ISPM) and its aftermath. This created tension between the space physics communities in Europe and the United States and explains why DISCO and SOHO were studied as purely European missions in their assessment phases. Despite interagency tension, the scientific communities on opposite sides of the Atlantic continued to cooperate in studying missions whose objectives were quite similar. At a regular ESA-NASA consultation meeting in June 1983, it was agreed that an integrated view should be taken of the large number of missions under study in the United States, Europe, and Japan in the area of solar-terrestrial physics. NASA and ESA therefore organized a preparatory meeting in September 1983, to which the Japanese Institute for Space and Astronautical Science (ISAS) was invited.

After extensive discussion and a rather painful rationalization process, the International Solar-Terrestrial Physics (ISTP) program was formulated. It embodied a reduced version of NASA's previous program, Origins of Plasmas in the Earth's Neighborhood (OPEN), consisting of four spacecraft: Wind, which measured the solar wind and space plasma properties near Langrangian point L1; Equator and Polar in near Earth orbits; and Geotail. New add-ons to the ISTP were Cluster and SOHO. In the preparatory meeting it was argued that SOHO and Cluster should be flown together. Both were addressing the same physical structures and processes by remotely sensing the coronal plasma through in situ measurements of the solar wind and in situ investigations in three dimensions of the magnetospheric plasma.

SOHO As Part of Horizon 2000. Formulation of the ESA science long-term program, later known as Horizon 2000, was a substantial community effort. It was guided and finally produced by a survey committee composed of senior European space scientists, including the ESA Space Science Advisory Committee (SSAC).

At the final meeting of the survey committee in May 1984 in Venice, Italy, only three cornerstones were originally foreseen. It was therefore a surprise when a fourth, consisting of the SOHO and Cluster missions, was introduced by the chairman of the Solar System Working Group. Inclusion of this cornerstone, however, balanced the Horizon 2000 program among the disciplines represented by active researchers at the time. This cornerstone was called the Solar-Terrestrial Science Program (STSP)[21] to make it a distinct element of the much larger International Solar Terrestrial Physics program.

[21] Originally called the Solar-Terrestrial Physics Cornerstone.

The dialogue with NASA achieved progress along several avenues, including the following:

- Provision by NASA of the SOHO launch using an Expendable Launch Vehicle (ELV);
- Agreement by NASA to transfer implementation of SOHO flight operations from the European Space Operations Center to NASA-GSFC, including use of the DSN for data retrieval;
- Provision by NASA of several spacecraft hardware items such as tape recorders, high-power amplifiers for both SOHO and Cluster, and Sun sensors for SOHO; and
- Provision by NASA of flight model environmental test facilities for SOHO (an option subsequently not taken up by ESA).

Summary

There were several problem areas for SOHO, which is natural for such a large cooperative project. For example, running a joint ESA-NASA AO for SOHO investigations proved extremely cumbersome.[22] There were scheduling delays, specification failures, and late deliveries of some of the hardware (tape recorders and detectors). In addition, the division of responsibility between ESA and NASA on the development of space and ground elements of the mission caused some initial problems and required that both parties adapt. In the end, these problems were solved satisfactorily for all involved and confirmed the need for clean interfaces in cooperative missions on all levels, from the experimenters to the agencies.

The scientific output now being demonstrated by the SOHO mission clearly shows how the insistence and will of a cooperative spirit eventually bears fruit. SOHO as it exists today could not have been carried out in a timely manner without cooperation between ESA and NASA. The contributions from national funding agencies in Europe and from the scientific and technical communities on both sides of the Atlantic were crucial. Finally, the cooperative effort on SOHO was exemplary, especially because it emerged in a climate where agency-level cooperation was at its coldest.[23]

International Gamma-Ray Astrophysics Laboratory

Introduction

The International Gamma-Ray Astrophysics Laboratory (INTEGRAL) mission was selected by ESA in June 1994 as the second medium-size mission (M2) of the Horizon 2000 long-term plan for space science. INTEGRAL, now planned for launch in 2001, is a high-energy observatory for fine spectroscopy and imaging in the energy range between 15 keV and 10 MeV. The payload consists of two main gamma-ray instruments; the Spectrometer on INTEGRAL (SPI) and the Imager on Board the INTEGRAL Satellite (IBIS); and two monitoring instruments, the Joint European X-ray Monitor (JEM-X), and the Optical Monitoring Camera (OMC). Design of the INTEGRAL instruments is largely driven by the requirement to establish a scientifically compatible payload.

Each of the main gamma-ray instruments, SPI and IBIS, has both spectral and angular resolution, but they are optimized differently to complement each other and achieve overall excellent performance. The two monitoring instruments, JEM-X and OMC, will provide complementary observations of high-energy sources at x-ray and optical energy bands.

Historical Background

The selection cycle in Europe followed a two-step competitive process, beginning with an initial call in June 1989 for new mission proposals in the ESA framework of the second selection cycle (M2) of the Horizon 2000 long-term plan. These proposals were narrowed down to six candidate missions in February 1990. The INTEGRAL mission concept arose from an earlier concept, GRASP (Gamma-Ray Spectroscopy and Positioning),

[22] The joint AO process was replaced by coordinated AOs for Cassini.
[23] Large parts of this write-up are based on published materials by M.C.E. Huber et al. in *ESA Bulletin*, May 1996, and articles in the special volume "The SOHO Mission," *Solar Physics* 162, 1995.

which had been studied by a consortium of European gamma-ray astronomers (primarily from the United Kingdom, France, Germany, and Italy). GRASP was submitted to ESA in response to a call for new mission proposals issued in July 1985. Phase A was carried out from December 1987 to October 1988; it was presented in April 1989 to the scientific community, but the mission was not selected by ESA.

The renewed discussions of INTEGRAL in Europe following the rejection of GRASP stemmed in part from the NASA Explorer competition of 1989 in which a U.S. gamma-ray spectroscopy mission, the Nuclear Astrophysics Explorer (NAE), had been selected for a Phase A study but then was not selected for flight. The early definition of INTEGRAL attempted to combine the best features of the two earlier gamma-ray missions studied on both sides of the Atlantic: GRASP (continuum spectroscopy and imaging) and NAE (nuclear line spectroscopy).

Cooperation

In June 1989, in response to the ESA call for new mission proposals, INTEGRAL was proposed jointly by individuals at the University of Southampton and the University of California, San Diego, on behalf of a consortium of institutes and laboratories in Europe and the United States. It was envisioned as a fully shared ESA-NASA partnership, a view supported by NASA Headquarters.

INTEGRAL was proposed with the same objectives as GRASP but with new designs for the instruments (fine spectroscopy was proposed as a separate instrument). International participation in INTEGRAL was widened with the addition of new U.S. and European institutes. As mentioned previously, INTEGRAL was among the six candidate missions selected by ESA in February 1990 for an assessment (pre-Phase A) study. An assessment study team was assembled mostly from astronomers in the United Kingdom, France, Germany, Italy, and the United States in approximately equal numbers. This team, together with ESA and NASA engineers, carried out a joint ESA-NASA assessment study that identified two options for an ESA-NASA cooperative mission, one in which ESA would provide the spacecraft and NASA the launch vehicle (Titan-class would be required), and the other in which NASA would provide the spacecraft and ESA an Ariane launch. In both options the scientific payload would be shared between ESA and NASA and would consist of two primary instruments: a cesium iodide imager (from ESA) and a germanium spectrometer (from NASA). These instruments would be supplemented by x-ray and optical monitors supported mainly by ESA member states.

In April 1991, INTEGRAL, together with other candidate ESA missions, was presented to the scientific community at large; it was subsequently recommended for a Phase A study with the highest priority by both the AWG and the SSAC. In June 1991, the SPC approved the selection of INTEGRAL with three more candidate missions for Phase A studies. In the same time frame, NASA confirmed its support of a Phase A study activity on INTEGRAL. NASA also indicated that the anticipated U.S. participation in the INTEGRAL mission would be proposed in response to its next Delta-class Explorer AO. If selected as M2 by ESA, NASA would seek an appropriate launch vehicle to lift INTEGRAL into the desired orbit.

In December 1991, the Russian Academy of Sciences offered to provide a Proton launcher, free of charge, as a contribution in exchange for a share of the observing time. This offer relieved NASA of launch vehicle responsibility and must have been viewed with relief. At the time, the United States was involved in supplying INTEGRAL's spectrometer (about $70 million) and possibly a Titan III launch. The launch issue was perhaps considered unrealistic.

The joint Phase A study was performed in 1992. As a result of its offer and because of cost considerations and optimized scientific return, Russia participated as a full partner in the study, with the Proton as a preferred launch option (since it would allow a higher orbit)[24] and an Ariane as a backup. In the early phases, various cooperative scenarios were considered. However, it soon appeared that the only feasible scheme was that ESA would provide the spacecraft, operations, and ground segment and would assume overall mission responsibilities. A highly eccentric orbit was selected, which allows use of the XMM (X-Ray Multi-Mirror Mission) spacecraft, thus

[24] The Titan launcher would provide for a 48-h orbit (28.5 degrees inclination, 40,000 km perigee, 117,000 km apogee), whereas the Proton rocket would give a 72-h orbit (51.6 degrees inclination, 48,000 km perigee, 115,000 km apogee).

reducing the cost of the mission. NASA's contribution would consist of one main instrument (the spectrometer) and one or two additional ground stations.

At a public presentation of M2 Phase A results in April 1993, NASA reaffirmed its support for INTEGRAL and its strong desire to participate in the mission, if selected by ESA. Funding would be sought through the international payload line, which had recently been established (although not permanently) at about the $10 million level per year. The stability of this budget line was somewhat uncertain at the outset. Moreover, NASA had not previously identified INTEGRAL in its overall mission planning. Given this uncertainty, NASA was unable to make a firm commitment. More importantly, the international payload line could not support the full cost of the spectrometer. It was already mortgaged for other programs (e.g., U.S. instruments on the Russian Spectrum X-Gamma mission), and the spectrometer was expensive (almost $70 million) relative to the size of the funding line. A suspicion arose within the U.S. space science community that funding the spectrometer would require that funds be derived from the Explorer line.

Again, within ESA's advisory structure, INTEGRAL was recommended for selection by the AWG and subsequently by SSAC. At ESA's June 1993 meeting, the SPC approved INTEGRAL as ESA's M2 mission, based on an international cooperation in which Russia would provide the Proton launcher and NASA the spectrometer instrument, as well as a contribution to the ground segment. At this time NASA was informed of the INTEGRAL situation, including the major role of U.S. teams in the spectrometer, which was similar in overall design to the instrument studied for Phase A of the NAE mission.

During the preparation (1993 to 1994)[25] of the AO for the instruments, ESA and NASA discussed the form of the AO and agreed that it would be an ESA AO open to the U.S. community for a possible NASA-funded spectrometer proposal. During the period leading to release of the AO, the possible level of NASA support for the spectrometer became increasingly uncertain. The INTEGRAL mission had still not garnered broad U.S. support or a vocal constituency in the NASA space science advisory process for several reasons: (1) the perception that INTEGRAL had never passed the required peer review in the Explorer competition, because the underlying rationale for U.S. participation (the spectrometer based on NAE) had not been selected for flight in the earlier (1989) Explorer competition; (2) its significant strain on the budgets of both the Explorer and the international payload line (which could have effectively bypassed the Explorer queue) in the NASA budget; and (3) early concerns of some astrophysicists that the lack of detection of bright discrete sources of line emission (e.g., 511 keV) by the Oriented Scintillation Spectrometer Experiment (OSSE) instrument on the Compton Gamma-Ray Observatory (CGRO), which had not confirmed at least one source claimed by SIGMA and, more importantly, had not found new line emission sources, implied that the spectrometer planned for INTEGRAL might not be sensitive enough. It therefore soon became clear that NASA would not (and could not) support the spectrometer at the level needed to have a principal investigator from the United States on the mission and that NASA participation would decrease significantly.

The AO was released on July 1, 1994, with proposals due by December 5, 1994. During the autumn of 1994, a meeting was held in France at which a NASA representative presented the astrophysics program. INTEGRAL was not included as a U.S. international program. Despite attempts by ESA and the U.S. and European scientific communities to change this situation, it became increasingly clear that NASA could not support INTEGRAL at the $70 million level expected by U.S. PIs. Possible levels of NASA participation ranged between $6 million and $20 million. Finally, in September 1994, a meeting between ESA and NASA led to the conclusion that NASA could not support the U.S. spectrometer PI. In the time remaining for preparation of the proposal, the French and German groups, originally involved with the principal investigator from the United States, prepared a European-only proposal for the spectrometer that just met the deadline.

This proposal was made possible because the Centre National d'Études Spatiales (CNES), the French national space agency, agreed to assume the financial burden resulting from NASA's withdrawal on the spectrometer, thus

[25] A first version of the Science Management Plan (SMP) was issued at the beginning of 1994, but SPC asked to reconsider the share of time between the principal investigator and guest observer for this observatory mission. An agreement was reached, and SMP was issued with a 6-month delay in June 1994.

safeguarding the scientific integrity of the INTEGRAL mission. Finally, NASA confined its reduced participation in INTEGRAL to small involvement in three instruments and the provision of one or two ground stations (still currently under negotiation with ESA).[26]

Summary

The withdrawal of NASA support for the development of INTEGRAL instrumentation was a near fatal blow for the mission. European PI teams were determined to recover the missing resources from their national funding agencies and keep the mission alive. Instrument teams were reorganized—in the cases of the imager, spectrometer, and optical monitor, with new PIs. New coinvestigators were added to replace lost resources. ESA organized a series of meetings whose purpose was to secure commitments from the national delegations that funding would be made available to the hardware teams. Each PI was responsible for lobbying the coinvestigator group. Although some funding problems remain, each instrument has successfully completed Phase A and B studies and flight hardware is now being developed. Despite the difficulties of obtaining broad consensus with the U.S. astronomical community, the gamma-ray community has provided considerable support and shared technology (e.g., for the germanium detectors and coolers). NASA is formally represented in the INTEGRAL Science Working Team by a mission scientist and also supports several coinvestigator scientists who are directly involved in developing the instruments. These coinvestigators have made significant contributions in each case.

Lessons Learned

Astronomy is an inherently international science with a long tradition of shared observations and joint planning. This cooperation developed from the need to observe objects over the full sky and at all times of day (or night). Thus, astronomers have long traveled to observatories around the world and in both hemispheres and have arranged for joint campaigns to observe and study objects regardless of local time zones. In the era of space astronomy and astrophysics, there has been this heritage to draw on. The space astronomy communities in the United States and Europe are also well integrated and accustomed to using joint facilities (e.g., HST, ROSAT, SOHO) for research, regardless of the program or agency originally responsible for the mission. However, this natural and historical set of connections has not always meant that planning for missions is as smooth as it might be in an era where large missions will increasingly require international cooperation. Astronomy is special in this regard; also by virtue of the need either to observe increasingly faint objects or to obtain even finer resolution (both spectral and spatial), astronomy research conducted in space will require larger missions for many of its long-term objectives. An understanding of the cosmos cannot be simply squeezed into a larger number of ever-smaller missions (although many opportunities for cutting-edge science on Explorer-class missions still remain), and large observatories or facilities (e.g., interferometers) will be needed in space. The astrophysics lessons learned, as described below, will therefore be critical not only to the future of international cooperation in space in general but also for progress in space astrophysics in particular.

Clearly Defined and Significant Mission Responsibilities

During the SOHO mission development phase, a clear understanding arose between NASA and ESA of how responsibilities were to be shared. The costs of SOHO were to be shared nearly equally between ESA and NASA

[26] Ballmoos, P., Dean, A.J., and Winkler, C., "Proceedings of the 17th Texas Symposium," *Ann. New York Acad. Sci.* 759:401, 1995; Carli, R., et al., *Proceedings of the 2nd INTEGRAL Workshop* (ESA SP-382), European Space Agency, Paris, 1997, p. 581; Courvoisier, T., "The Astronomical Community and the INTEGRAL Mission," *Proceedings of the 2nd INTEGRAL Workshop* (ESA SP-382), European Space Agency, Paris, 1997, p. 581; Gehrels, N., et al., "The INTEGRAL Core Programme," *Proceedings of the 2nd INTEGRAL Workshop* (ESA SP-382), European Space Agency, Paris, 1997, p. 587; Matteson, J.L., Dean, A.J., and Winkler, C., "Proceedings of the 2nd Compton Gamma-Ray Observatory Symposium," *AIP* 294:89, 1994; Winkler, C., ed., "Report on INTEGRAL Phase A Study," *ESA SCI* 93:1, 1993; Winkler, C., "INTEGRAL: Overview and Mission Concept," *ApJSS* 92:327, 1994; Winkler, C., "Proceedings of the 4th Compton Gamma-Ray Observatory Symposium" (in press).

to cover the development of the spacecraft on eventual mission operations. ESA retained overall responsibility for implementation of the SOHO project, which proved to be a determining factor in mission success. ESA took the lead in developing and integrating the spacecraft, whereas NASA undertook launch and mission operations. Interfaces between the agencies were extremely clean with well-defined responsibilities. Although the joint AO for instruments was difficult to implement, the determination of the PIs and the agencies overcame the difficulties. In addition, contributions from national agencies in Europe and from scientific and technical communities on both side of the Atlantic proved crucial.

Clear definitions of mission responsibilities also contributed greatly to the success of ROSAT development. For example, the direct access the U.K. project team had to the spacecraft contractor (Dornier), to GSFC, and to MPE minimized unnecessary levels between personnel on each side of the various interfaces. For formal and informal communications between the German and U.K. project teams, there were straightforward, clearly defined points of contact with neatly delineated responsibilities. In Germany, scientists were responsible for the science, including design, construction, and testing of the instruments. Managers at DLR-PT were responsible for controlling industry and funds; and the scientific-technical aspects were supported by MPE. There was a free flow of technical interactions between MPE and industry, along with good relations and cooperation between scientists and managers in all phases of the project. Moreover, for ROSAT, the modest added cost of the HRI by NASA greatly extended mission scope and utility.

For HST it is clear that ESA's responsibility not only for the solar arrays but also for an important instrument (FOC) helped solidify the mission in Europe and, even more importantly, strengthened the bond between NASA and ESA.[27]

Public Perceptions

Particularly since Hubble's repair with the Shuttle servicing mission in December 1993, HST has been a public space spectacular. This may have been a two-edged sword. NASA and U.S. scientists have received much credit for the success, whereas ESA and European scientific users have not been lauded as widely. This is true in both the United States and Europe and reflects a limited public understanding that space missions can be truly cooperative and international.

It is unclear that ESA will be able to support the development of a replacement instrument for the FOC, which could be supplied in the final servicing mission planned for 2002. (NASA has committed to providing the Cosmic Origins Spectrograph as a follow-on to the FOC.) Without a follow-on instrument from ESA, or significant contribution to HST hardware, will the Hubble remain a truly international mission? Planning at both the mission and the agency levels should include provisions for possible changes in mission status.

Strong Community Support Coupled with Broad Community Participation

ROSAT has been an enormously successful mission—not only because of its scientific successes, but also because of the huge numbers of participants outside of the hardware producers who have taken part in the observing program and have used data archives. In terms that appeal to scientific managers, ROSAT was a cost-effective mission. This result was anticipated when the mission was planned and played a key role in its selection by funding authorities in the United States and Europe.

The SOHO mission was, from its inception, strongly supported by the astrophysics communities in the United States and Europe. The mission payload was developed over a period of years during which concepts for complementary instrumentation presented scientific possibilities richer than the sum of individual components would imply. In addition, there was solid support for the mission within NASA and ESA. The HST effort was generally consistent with this experience, whereas INTEGRAL shows what happens when this broad and strong community support is not enjoyed on both sides of the Atlantic.

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[27] ESA also participated in the Science Operations Facility at the Space Telescope Science Institute in the United States and set up its own Space Telescope–European Coordinating Facility (in Garching, Germany), which further clarified mission responsibilities.

The European high-energy astrophysics community was solidly behind INTEGRAL. Although the predecessor U.S. Explorer-class mission, NAE, was favorably mentioned in the decadal study (Bahcall report),[28] the broad astronomical community either was generally unaware or had not been persuaded that NAE, as reconstituted in INTEGRAL, should be the next Explorer-class mission. NASA initially supported the mission (e.g., U.S. participation in the Phase A study) without having identified the resources necessary to carry it through. The mission did not receive as high a recommendation from NASA's internal advisory bodies as it did in ESA; moreover, the breadth of support appears in hindsight to have been lacking, and this could not be offset by strong support in Europe. The fact that NAE had not been selected meant that many in the U.S. community did not believe that a significant NASA role in INTEGRAL had passed peer review and was therefore justified.

In the United States, the INTEGRAL mission had a more limited community. What was presented as an observatory mission with extensive possibilities for drawing in large segments of the ground- and space-based observing communities was not perceived this way by U.S. astrophysicists because of the long observing times typical of gamma-ray observations. This meant that relatively few observations would be carried out in the course of the mission and appears to have been a factor in the NASA decision to withdraw from INTEGRAL. In any case, it was clear that only a relatively limited community would likely make observations with the INTEGRAL observatory. In addition, as noted above, some segments of the U.S. astrophysical community were concerned that the nuclear line sensitivity achieved with INTEGRAL would simply not be enough to achieve the desired breakthroughs and a future, more sensitive mission was needed instead.

Strong National Ties

ROSAT is a case mission showing that nation-to-nation international cooperation can be successful and sometimes easier to manage than NASA-ESA missions. For the ROSAT mission, strong and well-organized scientific groups existed in each of the participating countries (Germany, the United Kingdom, and the United States). The European high-energy astrophysics community had been involved in all NASA missions since the first x-ray satellite, the Small Astronomical Satellite 1 (SAS-1), called Uhuru, the Swahili word for "freedom." British scientists had worked on their own ARIEL series of missions and were also hardware providers for AXAF instrumentation. German scientists had developed x-ray technology through a series of rocket flights. Both groups had participated in the development of ESA's European X-Ray Observatory Satellite (EXOSAT) mission. NASA was kept apprised of these activities by the U.S. community. The ROSAT cooperative effort resonated strongly with U.S. government policy with respect to two long-term allies in Europe, Germany and the United Kingdom. Does this mean that nation-to-nation missions are more successful than NASA-ESA missions? This study unearthed no firm evidence for such a generalization; nation-to-nation cooperation may fail, as demonstrated by the Comet Rendezvous Asteroid Flyby (CRAF) mission (United States-Germany), which is mentioned in the next section on planetary sciences. INTEGRAL, SOHO, and HST, for example, show that ESA-NASA cooperation can be highly successful and lead to top-level research.

Long-Term Commitment—The Memorandum of Understanding

The HST project was originally planned as a 15-year mission with an MOU that guaranteed ESA 15 percent observing time in exchange for supplying the FOC instrument, solar panels, and ESA staff at the STScI. Extension of the MOU is currently being negotiated between ESA and NASA and is complicated by the uncertainty inherent in mission lifetime, as well as by the provision of a replacement instrument for the FOC. In a cooperative major mission such as HST, there should be provisions for extensions of the MOU in the original mission agreements. The planned lifetime of the HST extended beyond the term of the first MOU. Both parties could have considered, in general terms, what to do to extend the cooperation while still allowing for potentially altered circumstances

[28] National Research Council, *The Decade of Discovery in Astronomy and Astrophysics,* National Academy Press, Washington, D.C., 1991.

within the partnership, including the inevitable changes in both agencies of personnel who may have negotiated the original agreements.

Inconsistent or Misaligned Schedules for AOs or Planning

The INTEGRAL experience shows that there may well be a fatal problem if schedules are not well aligned. ESA and NASA were at different places in their funding cycles and their plans to release AOs for new missions. Whereas ESA is fully committed to carry through on a mission once it has been chosen by the competitive selection process after the presentation of Phase A studies, a corresponding NASA decision would require that the mission be prioritized within an ongoing NASA selection process. The INTEGRAL Phase A study was carried out in response to an invitation from ESA, without an initial solicitation on the NASA side. After supporting the invited U.S. members of the Science Working Team and prospective U.S. PI team throughout the INTEGRAL study and Phase A processes, NASA withdrew support at about the time the AO was issued because there was no current mechanism for the mission to compete against other opportunities in astrophysics.

The difficulty inherent in the misalignment of schedules was apparent most recently on the Rosetta mission (see following section), where NASA had to shift its commitments to other components of the mission simply because it could not provide assurances on the schedule deemed necessary by ESA.

Need for Appropriate Budget Lines

INTEGRAL may highlight a gap in NASA's budget lines, but other missions (particularly with the new theme of "smaller, faster, cheaper") may point to similar difficulties in ESA.

It remains unclear how NASA can respond to an international call for mission participation. The closest it has, at present, is in "missions of opportunity." An investigator can now propose a mission of opportunity with a cap of $20 million under the Explorer line. This will be peer reviewed along with the normal Explorer proposals, which are asking for full funding. This mission of opportunity line is not a de facto international payload line; it could also respond to opportunities from other parts of the federal government as well as the private sector. The joint committee notes, however, that the cap would have been too low to support the INTEGRAL spectrometer.

PLANETARY SCIENCES

Planetary science has a rich history of international scientific partnerships that could justify a separate report. However, there have been few planetary missions of international cooperation, defined in this report to mean the combined efforts of two or more countries in an integrated project (large or small) to reach a common goal. Most international planetary projects to date have been executed by one country or entity, with minor contributions of hardware, software, and engineering and scientific expertise from another. The withdrawal of a minor participant would not have been catastrophic.

For the purposes of this report, two missions have been selected that are representative of international cooperation in planetary science in the fullest sense: (1) the Cassini mission with the Huygen probe, which is an ongoing joint project of NASA, ESA, and Agenzìa Spaziale Italiana (ASI, the Italian Space Agency) and (2) a generic Mars mission, which represents the failure to instigate a successful joint Mars mission over the past decade despite many attempts.

The Cassini mission is distinctive in that both ESA-ASI and NASA are making major contributions to the project in a respective cost ratio of 30 percent to 70 percent, and the ultimate success of this mission requires that each participant meet its commitments, even though the United States has overall responsibility for the mission. By comparison, Galileo and CRAF were essentially NASA missions. The German space agency (DARA) was initially going to provide the propulsion systems for CRAF and Galileo, one science instrument for CRAF, and three for Galileo. Following the cancellation of CRAF, the Galileo part of this plan was successfully implemented. The cometary missions Giotto and Rosetta are essentially ESA-led projects. NASA had a minor involvement in Giotto to provide DSN support and may provide instruments for the Rosetta orbiter as well as DSN support.

Cassini Mission with the Huygens Probe

Introduction

Cassini is a joint U.S.-European mission to the Saturn system with emphasis on its largest satellite, Titan. The mission consists of a Saturn orbiter, provided by the United States; the Huygens probe, provided by ESA; and telecommunication and microwave systems, provided by ASI. In addition, individual ESA member states and the United States contributed a total of 18 instruments for the Cassini orbiter and the Huygens probe. The scientific objectives are to conduct orbital remote sensing of Saturn's atmosphere, icy satellites, and rings; in situ orbital measurements of charged particles, dust particles, and magnetic fields; and detailed measurements with six instruments on the Huygens probe during descent through Titan's dense**,** nitrogen atmosphere to the surface. In addition, if the probe survives after landing, it will conduct surface science measurements. The Cassini mission will address scientific issues raised by the highly successful Voyager 1 and 2 flybys in 1980 and 1981. A representative summary of fundamental science issues follows:

- The thermal structure and composition of the atmosphere of Saturn and their possible impact on theories of formation of the solar system, evolutionary histories of the planet, the rings, and the satellite system;
- Atmospheric dynamics and the general circulation of a rapidly rotating planet, which obviously exhibits significant differences from Jupiter;
- Dynamo theory and the generation of the axially symmetric magnetic field;
- The configuration and dynamical evolution of the ring system and its interrelation with the satellite system;
- The nature of the surface of Titan and its atmospheric composition leading to important constraints on theories of formation of the Saturn system;
- The detection of prebiotic molecules in Titan's atmosphere, and possibly the determination of physiochemical processes that lead to their formation;
- The formation, internal configuration, and surface processes of icy satellites as well as their comparative study; and
- The configuration, composition, and dynamics of the magnetosphere of Saturn and its interactions with the solar wind, the satellites, and the rings.[29]

The Cassini mission was launched on October 15, 1997, on a Titan IV-Centaur vehicle. The trajectory requires Venus-Venus-Earth-Jupiter gravity assists to deliver the Cassini spacecraft to Saturn in June 2004. The Huygens probe will be released on the first orbit after orbital insertion approximately 22 days before the first Titan encounter-flyby. The primary orbiter mission lasts 4 years (approximately 60 orbits around Saturn).

Historical Background

The historical origins of the Cassini mission can be traced back to the Space Science Board (SSB) [Space Studies Board as of 1989] of the National Research Council (NRC) and its Committee on Planetary and Lunar Exploration (COMPLEX), which recommended in its 1975 report an in-depth exploration of the Saturnian system subsequent to the Pioneer and Voyager flyby encounters.[30] In 1980 the NASA Advisory Council formed the Solar System Exploration Committee (SSEC) to address the high cost of planetary programs and their long development times. During the summer of 1982, the SSB and the Space Science Committee (SSC) of the European Science Foundation (ESF) established the Joint Working Group (JWG) on Cooperation in Planetary Exploration for the

[29] Joint Working Group on Cooperation in Planetary Exploration, National Research Council, *United States and Western Europe Cooperation in Planetary Exploration*, National Academy Press, Washington, D.C., 1986, pp. 91-92.

[30] Space Science Board, National Research Council, *Report on Space Science—1975*, National Academy of Sciences, Washington, D.C., 1976.

purpose of creating a framework for joint space missions to planets and primitive bodies. Also in 1982, a French scientist initiated discussions of the possibility that France and the United States could join forces to conduct a mission to the Saturnian system in a manner analogous to the U.S. Galileo mission to Jupiter. Mission costs to France were too expensive, and the French scientist teamed up with a German researcher, along with 27 other European scientists, to propose to ESA a Saturn orbiter and Titan probe mission to be conducted jointly with NASA and referred to as Project Cassini.

In January 1983 the SSEC issued its report with four core missions recommended: the first, the Venus Radar Mapper (1988 launch); the second, a Mars Geoscience and Climatology Orbiter (1990 launch); the third, Comet Rendezvous Asteroid Flyby (CRAF)—the first mission to use the Mariner Mark II spacecraft; and the fourth, a Titan Probe-Radar Mapper using a modified Galileo probe. The latter could be combined with a Saturn orbiter mission based on the Galileo spacecraft. However, it became evident in early 1983 that NASA was unwilling to proceed with a U.S.-only mission to the Saturnian system. The principal reason was the high cost; only 3 years earlier, the SSEC had been formed to recommend cheaper, more cost-effective planetary missions, and a Galileo spacecraft gave the mission a "Cadillac-Mercedes" cost image.

The JWG set up an Outer Planets Study Team (OPST) in February 1983 to "construct plans for candidate Saturn system missions to be jointly carried out by ESA and NASA." A joint ESF-NRC assessment study by OPST was conducted during 1983 to decide on scientific objectives for the proposed mission (which were essentially the Project Cassini objectives) and to recommend a mission concept, model payloads, required technologies, launch opportunities, schedules, and costs for various orbiter spacecraft and probe designs. The OPST gave its highest priority to using the spare Galileo spacecraft, with ESA taking the lead in developing a new lightweight Titan probe. This recommendation was based on "the exceptional capabilities of the Galileo spacecraft, extensive altitude coverage with a lightweight probe, and the low mission cost associated with use of an existing spacecraft."[31]

Although this approach made sense financially, it was politically unacceptable because the SSEC report had just come out and proposed the generic Mariner Mark II spacecraft for deep-space missions to hold down costs. The Mariner Mark II spacecraft was never built, but the concept was attractive enough to encourage abandoning the spare Galileo spacecraft approach and, when coupled with subsequent funding problems, to delay a new start for the Cassini mission until the end of the decade. However, the Cassini project incorporated a significant heritage from developmental work on the Mariner Mark II spacecraft (which yielded reduced costs to the mission). It should also be noted that in these initial stages of international discussions and assessments, a European-supplied orbiter and a U.S.-provided Titan probe based on Galileo probe development were also considered as possible contributions to a joint Cassini mission.

After the culmination of OPST activity in 1983, a large group of scientists headed by a French researcher submitted a mission proposal to ESA in response to one of its periodic calls for proposals. A joint ESA-NASA assessment study was carried out in 1984-1985; meanwhile, executives of the ESA science program obtained approval of the Horizon 2000 long-term program. A new call for mission ideas was issued to select mission concepts for a Phase A study. Because of the lack of a NASA commitment, the Cassini mission was put on hold in the ESA system while a number of other missions were being assessed. This move by ESA to mesh schedules proved precisely the right action, given the political and budget realities. At the end of 1986, new candidates to become the first "medium mission" had to be selected, and solar system science was given the possibility of studying two missions at the Phase A level.

The Solar System Working Group recommended to the ESA executive that two Phase A studies be carried out during 1987-1988: one for an asteroid-comet mission called Vesta in cooperation with Russia and France (this mission resembled very closely the present international Rosetta mission), and Cassini. A few days later ESA's Space Science Advisory Committee (SSAC) met to select a maximum of four Phase A studies covering both astronomy and solar system disciplines. The Cassini-Titan probe was eventually recommended pending a final NASA commitment to the mission.

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[31] *United States and Western Europe Cooperation in Planetary Exploration*, 1986, pp. 88-128.

Meanwhile during 1986, COMPLEX stated that "highest priority for outer planet exploration in the next decade is intensive study of Saturn—the planet, satellites, rings, and magnetosphere—as a system."[32] With this endorsement, NASA was able to initiate a joint Phase A study with ESA. The results of this study, initiated in 1987, were published in the so-called ESA red report[33] in October 1988. On November 25, 1988, SSAC and SPC selected the Huygens project as the first medium mission in the Horizon 2000 long-term plan as ESA's part of the joint Cassini mission. The competing ESA missions were VESTA, LYMAN (a UV space observatory), QUASAT (a radio, very long baseline interferometer satellite), and the Gamma-Ray Spectroscopy and Positioning (GRASP) telescope. On the U.S. side, NASA continued definition studies on the CRAF and Cassini missions and advanced development work on the Mariner Mark II spacecraft during 1987-1988. Cassini was paired with CRAF as a single mission in early 1988 for a proposed new start in FY 1989. It was included in the president's FY 1990 budget request to Congress, and Congress finally approved the CRAF-Cassini missions in November 1989. NASA's budget for Cassini in FY 1990 was reduced from the initial request of $40 million to $30 million, and further cuts in the FY 1991 budget used up all contingency funds for that year.

Cooperation

In October 1989, two separate but coordinated AOs were issued by ESA and NASA for selection of the Titan Huygens probe and Saturn orbiter instruments, respectively. This was the first instance of separate AOs being issued for a joint mission, which was done to avoid the legal problems that characterized payload selection for the SOHO mission caused by the issuance of a joint AO. ESA selects payloads on behalf of its member states who finance flight instrument construction; NASA selects and pays for the instruments. This creates completely different legal environments. Since then, all ESA-NASA cooperative efforts have been implemented through separate but coordinated selections.

Originally in August 1988, in the new start presentation to then NASA Administrator James Fletcher, the launch date for Cassini was April 1996, after the scheduled launch of CRAF (set for August 1995), which allowed the Huygens probe to be tested at the Jet Propulsion Laboratory (JPL). (Subsequent changes in launch dates required direct delivery of the Huygens probe to Cape Canaveral.) The CRAF-Cassini Baseline Confirmation Review in January 1991 found a way to reduce the total development phase by having Cassini launch on November 28, 1995, and CRAF on February 6, 1996. On September 26, 1991, the U.S. House-Senate conference allocated $117 million[34] less than the amount needed for the CRAF-Cassini mission in 1992, which delayed the launch date for Cassini until October 1997 and CRAF to April 1997, with a total development phase cost of $1.85 billion. On January 29, 1992, the president submitted his budget without CRAF. Given the financial situations for both NASA and DARA (reunification of Germany created inherent financial problems), the German space agency made the inevitable mutual decision with the United States to cancel CRAF.

Budget realities also precipitated a request from NASA Headquarters to reduce all development phase costs associated with the Cassini spacecraft and resulted in several simplifications, including elimination of the scan platform in April 1992 for a savings of $250 million from the previous budget of $1.68 billion. The Cassini mission was restructured deliberately to have negligible impact on ESA's Huygen's probe and was presented to NASA on April 23, 1992, by JPL; NASA authorized the Cassini mission at its current budget of $1.4 billion and schedule on May 22, 1992. One then current hope in terms of the ordered reduction in development phase costs by NASA Headquarters was that "non-time mandated development costs," which could be moved to the mission operations and data analysis (MO&DA) phase, could be recovered later. However, this proved to be wishful thinking. The MO&DA budget of Cassini was reduced from $1.5 billion to $1.32 billion in July 1992 by the

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[32] Space Science Board, National Research Council, *A Strategy for Exploration of the Outer Planets: 1986-1996*, Committee on Planetary and Lunar Exploration, National Academy Press, Washington, D.C., 1986, p. 5.

[33] Cassini Phase A Report ScI 88:5.

[34] All budget figures for the Cassini mission have been kindly supplied by Ronald Draper, Jet Propulsion Laboratory, deputy project manager of the Cassini mission.

NASA Blue Team–Red Team Review. The Cassini project then reexamined the architecture and philosophy of MO&DA and at the MO&DA preliminary design review in November 1993 presented a restructured, cost-effective approach that reduced the budget to $976 million. It is difficult to project the impact of the reduced MO&DA budget on science objectives.

The Cassini mission almost suffered the "budget ax" in preparation for the president's FY 1995 budget request to Congress in January 1994 and during congressional deliberations in the summer of that year. Here, the international aspect of the Cassini mission was an extremely important factor in reversing almost certain cancellation of the mission. In a subsequent review (Recertification Review 3) of MO&DA costs, funding was reduced to $755 million in June 1994 and in NASA program operating plans for 1995 and 1996; this was then reduced further to its present $700 million for the JPL-managed total. However, when NASA Headquarters taxes and contingency costs are added to the JPL total, the overall Cassini mission funding is still $755 million.

The Cassini mission is a complex undertaking involving 16 European countries and the United States in supplying technology, hardware, software, and engineering and scientific expertise. To carry out this cooperative venture, a number of agreements were formalized, including (1) an MOU between NASA and ESA signed on December 17, 1990, and (2) an MOU between NASA and ASI signed on June 14, 1993 (an agency-to-agency agreement); to secure funding, this was elevated to a government-to-government agreement via the exchange of diplomatic notes in mid-1994, for design, development, and delivery of four Cassini orbiter components. The components are (1) the High Gain Antenna-Low Gain Antenna-1 Assembly, (2) a significant portion of the radio-frequency instrument subsystems, (3) about half of the Cassini radar, and (4) the visible channel of the visible and IR mapping spectrometer hardware and personnel. The two and one-half year separation between the two MOUs reflects the active role of JPL's Cassini management in working with ESA, whereas Italian contributions to Cassini escalated over time in response to additional NASA requests and significant delays in defining the terms of cooperation. Several reimbursable agreements were negotiated between NASA and individual European member nation agencies for unique space-qualified components for Cassini, which were not available on the open market. In the Cassini AO (NASA), scientists were encouraged to bring in international partners on their instrument teams to reduce costs to the United States. The science payload selected has 18 instruments, with 2 to 10 countries providing parts of each instrument. Letters of financial endorsement had to be requested from every country involved in the development of each instrument.

Summary

Since the Cassini mission is ongoing, it is not possible to give a postmission assessment of how well the cooperative efforts worked. Instead, the basic management structure of the Cassini mission and some preliminary perspectives from the European and U.S. points of view are described. NASA established a program office at its headquarters, headed by the Cassini program manager along with the program scientist.[35] The program manager is responsible for overall management of the mission and coordination with ESA. NASA also established a project office at JPL headed by the Cassini mission project manager[36] with overall responsibility for mission management and implementation. ESA established a Huygens project office at the European Space Research and Technology Centre (ESTEC) headed by the Huygens project manager with overall responsibility for management and implementation of the Huygens probe. The primary group for science advice to NASA and ESA project managers is the Cassini Project Science Group (PSG) cochaired by the Cassini and Huygens probe project scientists. All principal investigators, interdisciplinary scientists, and team leaders (along with project scientists and NASA's program

[35] For the purposes of this report, a *program manager* is an individual responsible for cost, schedule, and technical performance of a multi- or single-project program and who oversees the project managers for integrated program planning and execution. A *program scientist* defines the policy and scientific direction of a program, establishes the mission science and applications objectives, and guides the science team to ensure that the scientific objectives are met.

[36] For the purposes of this report, a *project manager* manages the design, development, fabrication, and test of a project. A *project scientist* is the scientist who coordinates with the program/project manager to ensure that the science requirements of an investigation are met.

scientist) are members of the PSG. In addition, an equivalent group, the Huygens Science Working Team, serves the same function for the Huygens probe. The PSG meets about three times a year; the ESA-NASA MOU specifies that at least one of these meetings must be in Europe. Unfortunately, although the letter of the MOU has been satisfied on this requirement, the spirit has not, in part because NASA foreign travel regulations restrict the number of U.S. scientists and engineers who can attend any given international meeting on NASA travel funds. Given the complexity and diversity of the various contributions from 16 European countries and the United States to the Cassini mission, the PSG has served scientists acceptably as a format to optimize scientific return and resolve the usual conflicts between the engineering and science sides of a mission.

From the U.S. perspective, ESA and ASI have provided highly dedicated personnel as well as excellent hardware and software for the Cassini mission, with considerable cost savings to the U.S. government and taxpayers and the potential for much greater scientific return from the mission. The overall costs of Cassini are shared, approximately 70 percent by the United States and 30 percent by European member nations. From a European point of view, Cassini gives the European planetary community an outstanding opportunity to be deeply involved in one of the major missions of solar system exploration. The Cassini mission enjoys broad-based scientific support because its objectives cover most of the important scientific issues concerning the Saturnian system and thus involves the entire planetary science community. In times of crisis, international MOUs have provided strong support for continuance of Cassini.[37]

Finally, as pointed out in the case study, the scientific community is fortunate that the Cassini mission with the Huygens probe was launched successfully on October 15, 1997. There were several occasions at which cancellation of the mission may have occurred. Both NASA and ESA took actions to maintain phasing of the mission within their decision process rules and constraints; where there is a strong will, such actions are possible. The successful launch of Cassini-Huygens was regarded as a miracle by some involved in the mission: The mission was very ambitious and its implementation was risky.

Generic Mars Mission

Introduction

The generic Mars mission (GMM) differs from most of the other missions in this study by being not a single specific mission, but a sequence of mission concepts—all of which were studied in detail (in four cases, right through Phase A in ESA)—none of which came to fruition. This discussion focuses on why so much effort was expended on designing a series of international missions to Mars without a positive outcome.

Within the solar system, Mars has long had a special appeal because of its resemblance to Earth, the variety of science issues it poses, the possibility that life might have appeared there, and its potential for eventual human exploration. As a result, all space agencies involved in planetary exploration have always been interested in participating in Mars exploration.

In recent years, an International Mars Exploration Working Group initiated by the Inter-Agency Consultative Group (IACG) has examined the science goals of Mars exploration, currently approved missions of different agencies, and the constraints on and desires of those agencies in terms of participating in future Mars exploration. The working group has formulated a tentative plan for Mars exploration for the next decade, which includes multiple missions to Mars at every launch opportunity and culminates in a broadly international network of stations at the 2003 launch opportunity.

At the time of this writing, different elements of the plan are in various stages of implementation. In 1996, Russian launch of a complex mission to Mars (Mars-96), including an orbiter, two small landers, and two penetrators, ended in failure. In late 1996, the United States launched Mars Surveyor, an orbiter that should

[37] Ronald Draper, Jet Propulsion Laboratory, deputy project manager of the Cassini Mission, and Dr. Dennis Matson, Jet Propulsion Laboratory, Cassini project scientist, are acknowledged for their help in providing general information and facts on the Cassini-Huygens mission.

recover most of the original Mars Observer objectives,[38] and Mars Pathfinder, a highly successful small lander with a robotics rover that landed on the surface on July 4, 1997. More broadly, Congress has approved a Mars Surveyor program with multiple launches at subsequent opportunities. In 1998, the Japanese will send a spacecraft to characterize the interactions of Mars with the solar wind (Planet-B). Discussions are also under way to design a Russian-launched mission in 1998 that includes a U.S. orbiter, a French balloon (recently withdrawn), and a Russian rover. For nearly a decade, ESA has been studying how an international network mission (i.e., a pattern of small landers on the surface, with similar or identical payloads) might be implemented in 2003, with NASA as the primary partner.

Historical Background

NASA missions to Mars extend to Mariner 2 in 1962 and concluded, temporarily, with the outstanding success of Viking in 1976. Europe came on the scene in 1980, when a Mars Orbiter mission called Kepler was successfully proposed to ESA as a Phase A study. At about the same time, NASA undertook a study of a similar mission called Mars Geoscience Climatology Orbiter and later known as Mars Observer. In 1985, a decision was made to link Mars Observer and Kepler to produce the first attempt at an international Mars mission, the so-called Mars Dual Orbiter.[39]

In 1993 a new ESA Phase A study was completed on a more ambitious joint mission with NASA, called Marsnet, to place surface stations on the red planet. A revamped version of the same project was studied in 1994-1996 under the name Intermarsnet. Other Mars missions were studied by NASA: Mars Aeronomy Orbiter, Mars Environmental Survey (MESUR), and Mars Rover Sample Return. Each involved considerable guest participation from Europe.

Thus, over a period of about 15 years, three fully cooperative missions to Mars (in the sense of having nearly equal proposed contributions) were studied to a high level. In addition, several studies either were carried out at a low level or were not truly joint because most of the funding was to come from a single international partner.

The GMM includes international aspects of all of these missions, which had the same destination and broadly similar or overlapping scientific objectives.

Description of Four Missions Kepler was to be a spin-stabilized orbiter in a highly eccentric polar orbit about Mars. Mars Observer was a three-axis stabilized polar orbiter in a close, circular orbit, 360 km above the Martian surface. The Kepler orbit was to come in so low that direct sampling of the upper Martian atmosphere would have been possible five times a day. The latitude of periapsis changed by about 1 degree per day, to give good global coverage during the course of the mission, including both polar regions. Launch of both spacecraft was planned for September 1993, but this target was achieved only by Mars Observer. Some argued for joint science objectives on the premise that two spacecraft would be required to operate simultaneously; however, the missions were independent, although coordination would have been beneficial.

The Marsnet mission was to consist of a network of small stations on the surface of Mars. The main scientific goals were determination of the internal structure of the planet, chemical and mineralogical analysis of Martian rocks and soils, study of atmospheric circulation and weather patterns, and determination of the exobiological conditions existing on the surface. The expanded Intermarsnet mission was to consist of a network of stations to be landed on the Martian surface, but it later included an orbiter around Mars carrying scientific instruments in addition to its data relay function for the landers. Complementary data obtained from orbit would have included atmospheric sounding and imaging, roughness radar measurements, and plasma environment monitoring. The main scientific goals of the mission would have been to study the internal structure of the planet; the surface

[38] The Mars Observer, launched in 1993, failed to reach Mars orbit and lost contact with ground control. NASA's current plans call for two Mars missions every two years.

[39] European Space Agency, *KEPLER: An Interdisciplinary Mars Orbiter Mission* (ESA Document No. SCI[82]5), ESA, Paris, 1982; European Space Agency, *KEPLER Mars Orbiter* (ESA Document No. SCI[85]6), ESA, 1985; European Space Agency, *MARSNET* (ESA Document No. SCI[93]2), ESA, Paris, 1995; European Space Agency, *INTERMARSNET* (ESA Document No. SCI[96]2), ESA, Paris, 1996.

morphology and geology at the landing sites; the geochemical and mineralogical analysis of Martian rocks, soils, and volatiles; the atmospheric circulation, structure, and weather patterns; the magnetic field and geodesy of the planet; and exobiological conditions during the planet's history.

Cooperation Attempts

Cooperation in the exploration of Mars is perhaps discussed more than any other large international space project, and it is the one with the highest public profile.

The Mars Dual Orbiter (Mars Observer and Kepler) concept originated from the Terrestrial Planet Study Group (TPSG) of the JWG of the National Academy of Sciences–National Research Council (NAS-NRC) and the ESF. This group, which worked from 1982 to 1984, endorsed a Mars Dual Orbiter mission based on two independent mission proposals that were considered separately by NASA and ESA. These were the NASA Mars Geoscience and Climatology Orbiter, later named Mars Observer, and the ESA Kepler Mars Aeronomy Orbiter mission. The study team argued that by flying both of these missions in close coordination and simultaneously around Mars for a significant period, enhancements of the overall science return would be achieved. The missions went forward as a pair of single-agency projects, with the intention of obtaining the benefits of coordination if both were selected. The Mars Dual Orbiter failed because of a lack of reciprocal support and the need for each partner to contribute. However, it represented a failure of international coordination rather than international cooperation because each contribution could have been carried out independently.

Marsnet was a community proposal in Europe, submitted to ESA in response to a call for new mission proposals for the next medium-size project (M2). The call was issued in June 1989 by the director of scientific programs in the framework of the new selection cycle of the Horizon 2000 long-term plan. After evaluating all proposals concerning solar system missions, the Solar System Working Group (SSWG) recommended Marsnet for a Phase A study, following the assessment study in 1990-1991. This recommendation was subsequently endorsed by the SSAC. The Phase A study was coordinated with NASA, in view of possible future cooperation on a joint ESA-NASA Mars network mission. NASA, in parallel, studied similar landers in the framework of the MESUR mission. The Marsnet and MESUR study teams kept each other informed and exchanged representatives at their respective meetings. However, neither MESUR nor Marsnet ever reached fruition.

Nevertheless, the concept of a network mission to Mars is still a scientific priority. The practical benefits of cooperation stem mainly from sharing the costs of comprehensive scientific investigations on Mars. The surface network, in particular, requires a large launch vehicle and a relay-mapping orbiter, plus sophisticated landing systems. The surface network approach is therefore intrinsically a fairly expensive venture for which cost sharing not only makes sense but may also be the only way to proceed cost effectively. Thus, the Intermarsnet began immediately after cancellation of Marsnet. The Intermarsnet mission was submitted to ESA in response to a call for new mission proposals for the next medium-size project (M3) issued in November 1992. After evaluation of all proposals concerning solar system missions, the SSWG recommended Intermarsnet for a Phase A study following the assessment study performed in 1993-1994. This recommendation was subsequently endorsed by the SSAC and the SPC.

The Phase A Study was conducted jointly with NASA, with the specific goal of a joint mission to be launched in June 2003. NASA's component was drawn from the Mars Surveyor program, which already had congressional approval. A joint ESA-NASA Intermarsnet Science Working Group was formed to support Phase A activities during 1994-1996 with engineering and industrial teams. A successful International Workshop on Intermarsnet was held on September 28-30, 1995, in Capri, Italy, to demonstrate a fundamental, deep interest in Mars exploration among the wide international scientific community. Before conclusion of the Phase A study, the new budget for the ESA science program was approved by the European ministers with a reduction of 10 percent (possibly becoming 15 percent) over 5 years. The need for cost reduction of the mission to be selected put the Intermarsnet mission in severe difficulties vis-à-vis competing missions. ESA's budget squeeze threatened to delay the European part of the project, whereas NASA believed it could proceed only if the original launch date was adhered to. The less complex, cheaper, and ESA-only COBRA-SAMBA mission[40] was eventually selected in place of

[40] The COBRA-SAMBA has been renamed the Planck Surveyor.

Intermarsnet as the third medium-size mission of the Horizon 2000 long-term program. Once again, ESA's involvement in the exploration of Mars was postponed. As consolation for the solar system community, the promise was made to reserve the next medium mission budget for planetary science disciplines.

Summary

None of the Mars missions described actually came into being as a cooperative project; therefore, no actual cooperation (on flight systems at least) can be described. Yet in scientific communities, and to a certain extent within the space agencies that conceived and developed mission proposals and carried out design studies, great enthusiasm and goodwill resulted in highly effective cooperation. This derived from mutual recognition of the importance, interest, and timeliness of the science goals for Mars, as well as interest in using a cost-benefit analysis of cooperation to achieve a sweep of objectives too expensive for one partner under most circumstances.

The reason for the ultimate failure of cooperation is much harder to diagnose. It should be noted that this was not the isolated failure of a desirable project but the failure of a whole sector of a high-profile section of space science that was pursued diligently over an extended period in several different forms by many committed people.[41] The following factors were among those that contributed to the unsuccessful cooperation:

- Inadequate coordination within the European planetary community;
- Distraction by domestic pressures to achieve other objectives, not specifically targeted by the joint mission, especially Mars Rovers (mainly in France, affecting Kepler) and Mars Sample Return (mainly in the United States, affecting Intermarsnet); and
- Serious difficulties in matching the mechanics of the selection process on the two sides of the Atlantic to achieve a realistic program.

Lessons Learned

The planetary science community is strong only in some of the large European countries, and U.S. solar system missions competing for ESA new starts face strong competition from astronomy missions. Averaged over all of Europe, the European astrophysics community is considerably stronger and more cohesively organized than its planetary science community. Even in the United States, where NASA revolutionized the discipline, planetary scientists must compete against a well-organized astrophysics community noted for decadal implementation studies that clearly lay out future directions for astronomy and are highly valued by Congress. In Europe especially, the planetary sciences community is not well coordinated and cannot practice the "cartel" approach used by astronomers. International cooperation in planetary science operates within this competitive space science environment. Any lessons learned must be understood in this context.

In October 1982, the JWG on Planetary Exploration of NAS-NRC and ESF formed the TPSG, which recommended the development of a Mars Dual Orbiter mission. Four months later, JWG formed OPST, which endorsed the Cassini mission as the priority for the next major planetary probe. Thus, Mars and Saturn system missions started on equal competitive footing with well-defined science objectives. Both missions progressed to Phase A studies (Kepler in 1982, Cassini in 1987-1988) and ended by competing against each other and two astronomy missions (Quasat and Lyman) for the ESA Horizon medium mission selection in 1988. In this competition, Cassini benefited from the extraordinarily successful Voyager and its heritage of international cooperation. Voyager had established strong working relationships among European and U.S. scientists as coinvestigators associated with the 11 instruments on board each spacecraft. Unlike some missions portrayed in this report, at the time of Horizon medium mission selection the Cassini and Kepler missions could not be faulted for inadequate preparation. In fact, both missions were well defined in terms of science, instruments, and orbits. Hence, by any standards, the proposals that emerged from strong joint working groups formed in 1982-1983 were mature and solid.

[41] The comments and suggestions of Professor P. Masson, Université De Paris-Sud, and Dr. Marcello Coradini, ESA Headquarters, Paris, regarding the Mars mission studies are gratefully acknowledged.

"Sink or Swim Together"

One thing that distinguishes the Cassini mission from the Dual Orbiter mission is the philosophy of international participation. Cassini was constructed as an international cooperative effort in a mode of sink or swim together. In contrast, the Kepler mission was constructed as an international coordination project in which ESA and the United States would separately pursue Kepler and MGCO (Mars Observer), respectively, but with enhanced science return if done concurrently. The two components of the Dual Orbiter mission went independently through their agencies' selection procedures, and the result is well known. The Mars Observer was launched and Kepler failed to materialize. Kepler's direct competition with Cassini involved the same scientific community, and lack of synchronization with the Mars Observer timeline led to the failed cooperative effort.

The Cassini mission in its sink-or-swim-together mode generated strong "lobbying and support" efforts on both sides of the Atlantic. This partnership ensured that the importance attached to this cooperative enterprise was communicated to individual space agencies, ESA, and the U.S. government. In particular, the European lobbying and support effort was extremely important and effective in attaining a new U.S. start for Cassini in FY 1990 and averting near cancellation of the Cassini mission during FY 1994. The letter from ESA Director General Luton to U.S. Vice President Gore was an essential action at a crucial stage in the mission and illustrates the potential importance of international cooperation for mission success (Appendix G). For the Europeans, a total expenditure of almost $0.5 billion on the Huygens probe and Saturn orbiter would have been wasted if the United States had failed to honor its international agreements. In this context, an important lesson learned about U.S. financial support of space science, with its annual budget cycles, is never to assume that an individual space mission is safe from budget reductions or elimination. A vigorous educational lobbying effort is needed every year, particularly when a new U.S. president assumes office. This lesson is now evident as a result of the events that occurred in late 1993 through the summer of 1994, when Cassini was in deep trouble.

Clearly Defined and Significant Responsibilities

The sink-or-swim linkage on Cassini was complemented by clean interfaces and significant mission responsibilities. For the Europeans, Cassini provided an outstanding opportunity for the European planetary community to be deeply involved in a major solar system exploration mission. From an engineering point of view, clear technical interfaces allowed ESA management to maintain independence and full control of Huygens probe development. For scientists, the construction of space instruments in the framework of worldwide consortia is nothing new and resulted in no specific Cassini-related problems. Although the total cost of this mission could be construed as greater for all the taxpayers of participating countries, the current economic and political realities are that an individual country can no longer pay for a Cassini-class planetary mission alone.[42] Thus, missions on this scale require international cooperation to share the cost. Given a choice between going it alone without a mission or international cooperation with one, the choice for space scientists is obvious.

Broad Community Support and Mission Cost

To put it simply, as the cost of a major mission escalates, the breadth and strength of community support for the mission must also escalate. Marsnet and Intermarsnet were both fairly expensive missions and could not be carried out by ESA alone, except perhaps as cornerstone missions. These occur only about every 5 years and are in a highly competitive environment with other disciplines requiring access to space. A mission on the scale of Marsnet or Intermarsnet might not have attracted sufficient support in Europe as a cornerstone because of the inbred commitment of a majority of European space scientists to experiments on small bodies, particles and fields, and dust. Given the strength of the astronomy community as well, it seemed likely that cooperation with the

[42] In other words, the cost to taxpayers in any one country is certainly less in a cooperative mode than it would be for that country to conduct the project without international partnerships.

United States was not just desirable but absolutely essential to the success of a Mars network mission. On the American side, there was concern in some quarters that by putting pressure on the budget line, support for Intermarsnet in 2003 might indirectly jeopardize its top priority, a Mars sample return mission in 2005. Despite strong and sincere support for Intermarsnet on both sides in the selection showdown, lack of a single-minded approach among the communities on both sides of the Atlantic, combined with the relatively high cost that was threatening to delay the launch date, in the end proved fatal.

In formulating the extension to the long-term ESA program now called Horizon 2000 Plus, European Mars exploration suffered incredibly from rapidly evolving international interest and scientific objectives. The search for life has been an underlying motive in Mars exploration and research for years, but the negative results from the Viking landers required the advocacy of Mars missions to be more circumspect. In 1994, European planetary scientists also had to propose a Mars mission scenario that could guarantee scientific originality 13 to 15 years after its conception. The United States, on the other hand, had the capacity to carry out a network mission unaided but, in the current climate of massive cost-cutting, saw clearly the fiscal benefits of international cooperation. Cost, then, was a main factor driving cooperation on the later joint Mars missions, although there was also a strong desire among scientists to work together to maximize the scientific return for a given level of expenditure, and to exploit the scientific expertise available from many countries that did not reside in any one nation alone. But it is fair to say that the mentality established during the Mars Dual Orbiter Mission of international coordination, rather than the Cassini partnership of "sink or swim together," has permeated subsequent planning for ESA-NASA Mars missions.

Schedule Alignments and the Mission Approval Process

In the ESA system, the Marsnet failure could also be attributed to the lack of approval of the NASA component at the time of ESA selection. The different ESA-NASA mission selection processes and schedules are especially difficult for missions that only require coordination. The recent selection of an ESA astronomy mission instead of a Mars mission could illustrate a potential problem in flight selection procedures for accomplishing U.S.-European cooperation. NASA selection is subject to an intense political and scientific process, which can often take years for a mission to reach NASA's highest space science priority, and still be subject to revocation. In contrast, ESA makes a permanent selection decision based on a kind of tournament at which all interested parties gather and campaign. On a positive note, ESA "slowed down" its process in 1983-1985 during the development of the Cassini mission and thereby better matched the schedule on the other side of the Atlantic. This proved very beneficial to the development and approval of the Cassini mission.

SPACE PHYSICS

Investigations in space physics—whether experimental or theoretical—are largely devoted to specific phenomena in space such as the physics of acceleration of charged particles, entrainment of magnetic fields by the solar wind, shocks of various types traveling in the interplanetary medium, radiation trapped in planetary magnetospheres, and elemental and isotopic composition of energetic particles from the galaxy that can be investigated only in a space environment. These and other basic mechanisms cannot be brought down to the scale of Earth laboratories; however, they are the "ground truth" for explaining phenomena on larger astrophysical scales such as the galaxy.

Space physics is also unique in that the instruments required are relatively small and are usually derived from the culture of experimental physicists working alone or in small teams. This culture also reflects the end-to-end approach with PI-based teams that design and build their instruments, participate in testing and launching, supervise data processing, carry out their research, and publish their findings. Thus, this is generally a different background from the astronomer relying on common instrument facilities (e.g., the HST) built and operated by others—in this case, their investigations begin after the facility is in space flight. These differences in culture are often reflected in how investigators and their institutions approach international opportunities.

Because space physics missions extend to the planetary magnetospheres (e.g., Mercury, Earth, Jupiter, Saturn) or to the outer reaches of the interplanetary medium and heliosphere in three dimensions, the spacecraft that carry a typical mix of space physics instruments can be costly. Consequently, international cooperative missions—including those by ESA and NASA, or nation to nation—represent the potential for significant cost sharing. It should also be noted that in space physics it is easier and often more effective to form international partnerships with individual instrument teams than in the case of large, complex, facility-class instruments.

From a historical perspective, the subdiscipline of space physics has a strong tradition of international cooperation, beginning in the early 1960s with Ariel-I and Ariel-II and the early Explorers. To date, there have been some 45 such missions that have had at least a partial focus on space physics. Perhaps the height of the modern era of this tradition, when the balance between European and U.S. participation within a given project reached contributions at the spacecraft level from both sides, along with closely integrated science, begins with the International Sun-Earth Explorer (ISEE-1, 2, and 3) program, launched in 1977-1978. Space physics on both sides of the Atlantic has benefited greatly from this cooperation, with subsequent projects such as the Active Magnetospheric Particle Tracer Explorer (AMPTE) and the ISTP as positive examples of such cooperation. Some programs have failed to live up to expectations, usually because of a breakdown in support for the program on one side or the other, a prime example being the ISPM, which was to have consisted of two spacecraft flown simultaneously over opposite poles of the Sun. The failure of this cooperation both shocked and dismayed participants on both sides of the ocean, who had considered the international aspect to be a buffer against just such a descope. The scaled-back version of this mission, Ulysses, has been very successful in its own right, but only for some of the goals of the original program.

In space physics, three missions have been chosen for discussion, from which different lessons may be taken. The ISEE-1 and ISEE-2 program, based on joint NASA-ESA cooperation, is a good (if perhaps historical) example of the mutual benefit, good-faith cooperation, and strong scientific product that can be achieved. The AMPTE program is likewise a highly positive example of a relatively small mission, in this case conducted bilaterally and later trilaterally (the United States and Germany at first, with the later addition of Great Britain), in which institutional relationships played the dominant role in the interaction. The third mission discussed is the ISPM, a program of ambitious scale that provides the first historical example of a breakdown in the teaming of NASA and ESA. The ISTP would have important, more current lessons to contribute, but it is not included here primarily because it is still going on and because unlike the three missions that are covered, the coordination is much looser, with responsibility concentrated in a particular agency at the spacecraft level. (This arrangement may, in fact, be considered the result of lessons learned from earlier cooperative ventures such as ISPM.) SOHO (an element of the ISTP) is, however, discussed as one of the examples in the section on astrophysics.

International Solar Polar Mission

Introduction

The heliosphere is a vast region totally enclosing the solar system and extending to approximately 100 to 120 astronomical units (AU) (one AU is equal to the distance between the Sun and Earth). The heliosphere is produced by the radial outflow of the solar-wind plasma from the Sun, carrying outward with it an extension of the solar magnetic field. This three-dimensional electrodynamical "bubble" interfaces with and is contained by the interstellar medium. Understanding of the physical processes occurring within the heliosphere was based, until 1992, on observations from Earth and spacecraft located within about 7° from the heliospheric equator. Only two spacecraft, Pioneer-11 and Voyager-1, reached 16° and 30° latitude, respectively, in the distant heliosphere. Thus, until spacecraft could undertake observations over a latitude range in the inner heliosphere extending from pole to pole of the Sun and heliosphere, the essentially two-dimensional world in the ecliptic zone had to be extrapolated, with assumptions used to make theoretical models for a three-dimensional heliosphere.

Because there are differences between the north and south hemispheres (e.g., solar activity, coronal magnetic fields) over the 11- and 22-year solar activity cycle, it was obvious that heliospheric dynamics would be neither static nor necessarily uniform over both hemispheres. Consequently, these time- and space-dependent asymmetries would require simultaneous investigations over both hemispheres of the Sun and heliosphere for observations of the solar wind, magnetic fields in the heliosphere, or incoming galactic cosmic rays, among other phenomena.

With these factors in mind, ISPM was planned to consist of two spacecraft, passing to and over opposite heliospheric hemispheres simultaneously in order to separate time and spatial changes that could complicate the analysis of heliospheric dynamics in three dimensions.

Ultimately, only one international spacecraft—Ulysses—was launched. It reached 80.2° south latitude in 1994, passed perihelion in March 1995, and reached 80.2° north latitude in mid-1995 under conditions approaching the solar minimum of the approximately 11-year solar cycle. The many diverse scientific investigations on Ulysses were hugely successful, and the resulting discoveries in many fields of space physics drastically changed many concepts that had been based on extrapolations from the two-dimensional world.

Historical Background

In the early years of scientific investigations in space it became increasingly clear that dramatic solar and interplanetary discoveries made near the ecliptic plane of the Sun and heliosphere could be fully understood only by extending observations to the polar regions of the Sun and heliosphere. However, in the 1960s—in both the United States and Europe—only a minor portion of the scientific community was concerned with this three-dimensional goal for space flight. This is understandable because of a major technical difficulty. In the 1960s, there was no propulsion system for a direct launch from Earth that could overcome the orbital angular momentum of Earth, which was necessary for a spacecraft launch out of the ecliptic to a high solar latitude.

By the early 1970s, driven by the goals of U.S. programs to investigate Jupiter and develop a galactic probe, scientists and engineers had solved the principal technical problems for a future out-of-ecliptic (OOE) mission. These solutions included the following:

- The radioisotope thermoelectric generator (RTG), instead of solar panels, for spacecraft power;[43]
- A gravity assist for a swing-by of Jupiter;[44] and
- Development of radiation-resistant electronics for penetration of the Jovian radiation belt.[45]

Attempts between 1972 and 1974 to convince NASA administrators to use the spare (backup) Pioneer spacecraft for an OOE failed (Appendix B) but did lead the administrator to discuss a possible international OOE mission with the ESA director general. In Europe, the method proposed in the 1960s and early 1970s for OOE was the development of a solar-powered ion propulsion engine to launch a spacecraft directly from Earth. When it became apparent that there would be no support for such engine development, there was strong motivation for ESA member states in 1973 to be interested in international cooperation with the United States.

To investigate the feasibility of a cooperative program between the European Space Research Organization (ESRO, now ESA) and NASA, ESRO appointed three European scientists and NASA appointed four U.S. scientists in 1974. This study group held alternating meetings in Europe and the United States in 1974 and 1975. A dual spacecraft mission was proposed that would maintain clean interfaces. This proposal, which became the ISPM, was accepted by ESA and NASA. The ESA spacecraft would be spin stabilized, whereas NASA's would be stabilized to accommodate a coronagraph. AOs to propose scientific investigations were issued by ESA and NASA in April 1977.

Cooperation

With a dual launch planned for the February 1983 window of access to Jupiter, ESA and NASA moved swiftly before U.S. congressional approval of ISPM to obtain spacecraft contractors, identify investigators, and define the instrument payload. The joint announcement in early 1978 of experiments selected for the two spacecraft revealed

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[43] Studies of RTG radiation on charged particle telescopes; Letters from J. Epstein, Goddard Space Flight Center, 1962, to Simpson and final report, May 1966.

[44] The success of Pioneer 10 in the December 1973 swing-by of Jupiter proved that this approach for an OOE mission would be successful.

[45] This problem persisted throughout the 1960s. Resolution of the problem enabled Pioneers F and G, now called 10 and 11, to be launched to Jupiter in 1972 and 1973, respectively.

the magnitude of interest in ISPM by the science community. More than 200 scientists from 65 universities and research institutions in 13 countries were associated with ISPM. The selection of experiments in early 1978 included a mix of ESA and NASA investigations on each spacecraft. The investigators moved ahead with enthusiasm, apparently unaware—until it was too late—of impending difficulties that would culminate in cancellation by NASA of the U.S. spacecraft containing both European and U.S. experiments.

In January 1978, the budget request for FY 1979 submitted by the president to Congress included the ISPM as one of five new starts. Congress approved it but effectively cut $5 million from the $13 million ISPM request to cover overruns in Space Shuttle development costs. NASA signed an MOU with ESA in March 1979 (Appendix C), but by year's end the chairman of the Senate Appropriations Subcommittee for Housing and Urban Development and Independent Agencies (which has budgetary jurisdiction over NASA) was suggesting to the NASA administrator that ISPM be delayed 2 years since Shuttle development was behind schedule and the interim upper stage (IUS), still to be developed for the Shuttle, probably could not launch the dual spacecraft. In response to this difficulty, it was recommended that the Centaur upper stage replace the IUS. Nevertheless, no action was taken to alter the mission until President Carter submitted an amended budget for FY 1981. This amended budget maintained the U.S. craft but proposed a postponement of the mission for 2 years, moving the launch from 1983 to 1985.

With the election of President Reagan came a change of White House policies in the Office of Management and Budget (OMB). The White House, under the usual practices of a new administration, recast the Carter budget in line with Reagan administration objectives. When the revised budget was released, OMB called for overall budget reductions within each NASA budget category for FY 1982, which resulted in $107 million less for the Office of Space Science and Applications (OSSA).[46] NASA chose to absorb a good portion of these cuts by eliminating the $43 million originally slated for ISPM in FY 1982. After initial release of the FY 1982 budget request in which these cuts were outlined, NASA made a token request for funds for ISPM that was turned down (see Appendix D).[47] Soon thereafter, Acting Administrator Hans Mark rejected the two-spacecraft option. This led to cancellation of the U.S. spacecraft, finalized by the conference vote on NASA's budget in late September 1981.

When the new NASA administrator, James Beggs, arrived in June 1981, it was essentially too late—his options to save ISPM were lost. This may seem somewhat confusing since Congress was still interested in an ISPM mission. In November 1980, Congress (at the urging of scientists) had requested that NASA have the National Academy of Sciences–National Research Council study ISPM mission options—options to be reported back to Congress before September 11, 1981. Congress expected this review to consider the scientific merits and all costs of the two-spacecraft options. Because the timing of the decision was critical, the congressional conferees expected to be briefed by the review panel on its recommendation by September 11, 1981.

Throughout late 1980 and early 1981, NASA staff prepared five options for an OOE mission, extending from a single ESA spacecraft to the full ISPM dual-spacecraft mission, with cost estimates for NASA funding (estimates from $110 million to $460 million; see Appendix E). Unfortunately, the NRC committee did not meet until July 1981 to consider these five options. Its report was submitted on September 9, 1981.[48] This tardy response to Congress was too late to serve the new NASA administrator. ESA was informed by Administrator Beggs on September 4, 1981—without prior consultation with ESA and before the expected congressional review—that NASA would not include a request for funds for the U.S. ISPM spacecraft in its FY 1983 budget proposal to be submitted to OMB.[49]

Summary

The cooperative effort for a dual mission obviously failed. There may have been a lack of belief in the community that the mission required two spacecraft, in other words, that it was essential to acquire bipolar solar

[46] Johnson-Freese, J., "Canceling the US Solar-Polar Spacecraft," *Space Policy*, February 1987, p. 24.
[47] Letter from the Office of Management and Budget to NASA, June 22, 1981 (see Appendix D).
[48] National Research Council, Committee on NASA Scientific and Technological Program Changes, *The International Solar-Polar Mission: A Review and Assessment of Options*, National Academy Press, Washington, D.C., 1981.
[49] As a result, only the first option of the five given in Appendix E—the single ESA spacecraft—was still viable.

data simultaneously. Specific factors also contributed to the unsuccessful outcome of NASA-ESA cooperation. Administration and congressional changes led to personnel turnover and the loss of several key administrators in 1980-1981. Consequently, these changes contributed to a lack of understanding of the importance of ISPM and of the consequences of cancellation of the U.S. spacecraft. Misunderstandings arose in Europe from a lack of understanding of the U.S. budgetary process. Although the MOU contained caveats indicating possible cancellations by NASA, it never clearly stated that the mission depended on yearly action by Congress. In addition, there were communication gaps among the scientists selected to perform experiments, the agencies, and Congress. Since the selection and mixing of ESA and NASA experiments on each of the two spacecraft had been completed in early 1978, scientists involved in the mission believed until early 1981 that ISPM was secure. Moreover, contractors for scientific instruments and spacecraft had made substantial cost commitments to ISPM, on both sides of the ocean, before the mission was submitted to Congress for approval. These investments resulted in large losses, both scientific and financial, when the spacecraft was canceled. Communications problems were further exacerbated when ESA was not consulted in the decision-making process on canceling ISPM. The hurt experienced by scientists and officials, especially in ESA states—both real and perceived—created a contentious atmosphere that influenced later cooperative efforts.

Finally, by early 1982, ESA and NASA decided to move ahead with the single ESA spacecraft containing the original 1978 mixture of ESA-U.S. investigations. NASA delays in launch vehicle development, followed by the *Challenger* accident, postponed launch of the ESA spacecraft until 1990. The mission, renamed Ulysses, resulted in important discoveries in its solar pole-to-pole passage in 1994 and 1995. NASA fulfilled its other commitments—12 ESA personnel, supported by ESA, are at JPL in charge of mission operations. An extended mission to return Ulysses to the solar polar regions in 2000-2001 was approved by ESA unconditionally in 1994 and by NASA in 1996, with a year-by-year caveat of possible cancellation (Appendix F).

Active Magnetospheric Particle Tracer Explorer

Introduction

The Active Magnetospheric Particle Tracer Explorer program was a three-nation, three-spacecraft mission. It was designed to study the sources, transport, and acceleration of energetic magnetospheric ions and the interaction between clouds of cool, dense, artificially injected plasma and the hot, magnetized, rapidly flowing natural plasmas of the magnetosphere and solar wind. The three AMPTE spacecraft were the NASA Charge Composition Explorer (CCE), the Federal Republic of Germany's Ion Release Module (IRM), and the United Kingdom Subsatellite (UKS), so termed because of its close proximity to the IRM and its launch configuration acting as the flange between the IRM and the booster. The three were launched together on August 16, 1984, into near-equatorial elliptical orbits. All contained extensive instrumentation supported by a diverse team of investigators, with the CCE and IRM providing the only complete data set existent on energetic ion spectra, composition, and charge state throughout the near-Earth magnetosphere. In addition, the IRM carried out eight major active ion releases—two clouds of lithium ions in the solar wind in front of the magnetosphere; two barium "artificial comet" releases in the dawn and dusk; and two releases each of lithium and barium ions in the near magnetotail. The UKS, which malfunctioned after 6 months, provided plasma, magnetic field, and plasma wave measurements. This satellite flew in close proximity to the IRM and was expected to provide information on the spatial scale of physical processes associated with ion releases.

Historical Background

The AMPTE mission was conceived in the early 1970s as a logical next step in understanding the energetics of Earth's magnetosphere. Composition studies had been going on for some years in high-energy cosmic rays. New and exciting results showed that many elements were represented, not just protons and electrons, and there were hints that charge states might be important and not necessarily as simple as expected.

In the magnetosphere, the radiation belts had been explored to the extent that the locus and energy distributions of ions and electrons were fairly well determined, with the plasma sheet mapped to a much lesser extent. Virtually nothing was known about the composition of the ions, their sources, their charge states, and the mechanisms that accelerated them to high energy (either from solar-wind energies or ionospheric energies). This was the next logical step in the exploration of the near-Earth space environment.

Along with the development of new time-of-flight techniques for measuring ion composition and charge state, the release of gases into the ionosphere and magnetosphere had been developed by German scientists at MPE. In these experiments conducted from rockets, fast-ionizing materials—mostly barium atoms—were released. For painting auroral magnetic field lines, shaped charges were used. Releases were timed so that while ground observers were in darkness, the gases expanded into sunlight where they were quickly ionized. A host of scientific applications existed for these artificial plasma releases, such as tracing the otherwise invisible magnetospheric convection or DC electric fields, tracing or even generating instabilities and the formation of ionospheric irregularities, and verifying the existence of electrostatic acceleration in the auroral region.

This combination of developments, it was argued, could be employed in experiments that combined the release of gases (barium and lithium, which do not occur naturally in the magnetosphere, ionosphere, or solar wind) with tracing of the ions, by use of a separate satellite with excellent instrumentation. The strategy was to release ions in the source regions for the magnetosphere (i.e., solar wind and geomagnetic tail) and place the tracing satellite well within the outer magnetosphere. In this way, it was hoped that the transfer efficiency through respective magnetospheric boundaries, as well as acceleration and transport processes, could be established.

Complementary to the magnetospheric particle tracing was the second objective, the diagnostics of the interaction between the natural plasma environment (solar wind, plasma sheet) and the dense, heavy ion population of the release gas clouds, by both in situ and remote (ground-based) sensing. There was particular interest in releases in the solar wind, because these would simulate the creation of cometary plasma tails (artificial comet experiments). A third objective was to use the plasma and field diagnostic instrumentation on both spacecraft to monitor the magnetospheric and solar-wind environment with model instrumentation, particularly the newly developed ion composition and charge state techniques.

The mission was considered an attractive concept, both because of its novelty and promise of ushering in a new, powerful technique for actively exploring space plasmas as well as for its timely goal of measuring the composition and charge state of the hot plasmas in the magnetosphere. Although no trace of any of the releases from the IRM was ever detected at the CCE, the release experiment gave rich information on the interaction between environmental and injected plasmas, owing both to onboard diagnostics on the IRM and the UKS and to remote sensing from various ground stations and airplanes. The detailed composition and charge state measurements throughout most of the equatorial middle magnetosphere by the CCE, and the assessment of dynamical processes in the near-Earth tail and at the magnetopause made by instruments of the IRM, remain valuable resources today.

Cooperation

The most important characteristics of the AMPTE mission from an organizational perspective were that it was led by two principal investigators (one from the Johns Hopkins University Applied Physics Lab [APL] for the United States and one from MPE for Germany) and that the spacecraft were developed in these institutions under the control of the PIs. At the same time, the PIs were responsible for their respective spacecraft, each of which carried multiple instruments (the UKS was, under this arrangement, considered an instrument of the IRM). Given this architecture, the PIs were better able to drive the science agenda and thereby foster and impose a common set of science objectives and collaborations. NASA oversaw the AMPTE project under the manager of international programs at GSFC, who was known for his strong management and his facility in moving AMPTE funds.[50]

[50] The AMPTE manager at GSFC set aside 15 to 20 percent as contingency funds and forced APL to spend more money to make the spacecraft more robust—for example, two transponders, redundant power converters, and a cold-gas altitude system in addition to magnetic torquing. Thus, the project contingency was used up-front for robustness, at the direction of the government.

The program also employed a new paradigm regarding data rights. Data from any instrument were available to any other and easily accessible through the AMPTE Real-Time Science Data Center, operated by the APL data reduction and analysis team. The data center was designed according to guidelines dictated by data rights and by the obligation to provide data equally to the entire science team.[51]

The mission began in 1971 as a concept expressed in two letters sent by APL to the magnetospheric physics chief at NASA. In the time between these two letters, Germany became involved, and the mission proceeded for several years as an extended study on both sides of the Atlantic. In 1976, the mission proposal was submitted to NASA in response to Explorer AOs 6 and 7. In 1977 it was selected jointly along with the Solar Mesospheric Explorer (SME) and the Infrared Astronomical Satellite (IRAS). Because of IRAS cost overruns, hardware building for AMPTE was delayed on the U.S. side until 1981 when the start of Phase C/D was funded by NASA.

Germany had begun building the previous year, and the MOU between Germany and the United States was signed in the fall of 1981. The UKS was conceived, after the failure of the Firewheel Ariane launch, to enhance in situ diagnostics during the gas release phases, as well as at natural boundaries such as the magnetopause. British participation interfaced with the project through Germany. According to the MOU, the UKS was formally considered an IRM experiment.

The three spacecraft were launched in 1984 aboard a Delta and were successfully placed in their intended orbits. The UKS failed 6 months into the mission; the CCE and IRM survived and completed the primary mission.

Summary

With its state-of-the-art composition and charge state instrumentation, AMPTE was very successful in its science goals of investigating the composition and charge state of the energetic ions throughout the inner and middle magnetosphere, in determining the dynamical processes at the interface between the solar wind and the magnetosphere, and in exploring the near-Earth magnetotail. Although initially conceived as a highly focused and modest space physics mission, like the successful ISEE mission, the CCE and IRM spacecraft proved to be important tools in the exploration and long-term monitoring of interaction processes between the solar wind and Earth's magnetosphere and atmosphere, and the resulting changes of particle populations and field configurations. The scientific success of the AMPTE mission was due, in part, to the science data system, which originally allowed on-line access to all of the data by all coinvestigators and guest investigators. Today, it is open to general access by the space physics community and is still being used very actively (more than 500 publications have been based on the AMPTE data set, with more being submitted every year).[52]

Good communications between and among mission participants, agencies, and political entities contributed to AMPTE's success. Educating and maintaining contact with political players also proved critical. Efforts by mission leaders in the United States to foster political support and work with both Senate staff and NASA management helped secure start-up funding for AMPTE. Similarly, the PIs' political involvement was important in keeping the mission on track. They acted effectively at a congressional level when trends adverse to the mission arose.

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[51] Although data were accessible by all the PIs, their use in publications was subject to the individual instrument team leader's permission. This permission request was, for the most part, simply a courtesy but was always observed. The practice was viewed as a safeguard against people analyzing data they did not fully understand and interpreting as actual geophysical events what might be instrumental glitches.

[52] The section on AMPTE was compiled from the following sources: interview with Dr. Stamatios M. Krimigis, department head, Space Department, the Johns Hopkins University Applied Physics Laboratory, Laurel, Md., 1996; John Dassoulos, AMPTE Program Manager, the Johns Hopkins University Applied Physics Laboratory; and contributions from Prof. Gerhard Haerendel, PI, Max Planck Institute für Extraterrestrische Physik, Garching, Germany. Other references include the AMPTE website,<http://sdww.jhuapl.edu/AMPTE/ampte_mission.html; IEEE, *Transactions on Geoscience and Remote Sensing* (GE-23), 1985; Memorandum of Understanding Between the United States National Aeronautics and Space Administration and the Federal Minister for Research and Technology of the Federal Republic of Germany on the Project of the Active Magnetospheric Particle Tracer Explorers, October 15, 1981; Department of Housing and Urban Development, "Independent Agencies Appropriations Bill 1981 Report," which accompanied H.R. 7631, specifically appropriating start-up money for AMPTE; letters from S. M. Krimigis to Dr. E. R. Schmerling, Magnetospheric Physics Chief, NASA, June and September 1971.

International Sun-Earth Explorer Mission

Introduction

The International Sun-Earth Explorer mission introduced a novel feature into solar-terrestrial and space plasma research, a dual-spacecraft approach to the measurement of crucial boundaries or small-scale plasma structures, plus monitoring of these conditions about 1 hour ahead of their arrival at Earth's magnetosphere, where the spacecraft pair was operating. The spacecraft pair ISEE-1 and ISEE-2 were launched jointly on a Thor Delta 2914 from the Eastern Test Range in October 1977. The apogee was 146,000 km and the perigee 700 km, with about 30-degree inclination. ISEE-3 was launched in August 1978 and inserted into a halo orbit around the libration point 1.5×10^6 km upstream of Earth. Later it was placed in the far tail and was finally redirected as the International Cometary Explorer (ICE) to intersect the tail of comet Giacobini-Zinner in September 1985. The ISEE-1 and ISEE-3 spacecraft were built by NASA, based on the very successful Interplanetary Monitoring Platform (IMP) design; ISEE-2, a smaller spacecraft, was built by ESA and carried the thrusters for station keeping with ISEE-1. The payloads of all three spacecraft were carefully adjusted to each other for optimum coverage of all relevant plasma, field, and high-energy particle parameters. The instrument PIs on all three spacecraft were from the United States and Europe. From a total of 80 proposals, 31 instruments were selected by a joint NASA-ESRO selection committee. The mission was extremely successful and led to many discoveries and to deeper understanding of crucial plasma processes. For years the total production of papers arising from this effort exceeded 100 annually. Even as late as 1996 there was still a steady flow of papers based on ISEE data.

Historical Background

The origin of the two-spacecraft concept can be traced to 1968-1969 when discussions began in the United States on the possibility of realizing a satellite pair IMP K-K′. At the same time, a British scientist was trying to promote in Europe the idea of a cluster of satellites. The NASA project scientist on ESRO II at the time brought this idea to ESRO, and soon the idea of a joint NASA-ESRO mission was born. In early February 1971, during a joint NASA-ESRO program review in Washington, D.C., the idea was officially discussed and introduced into the ESRO scientific advisory system. With positive recommendations from the respective advisory bodies on both sides of the Atlantic, a joint NASA-ESRO AO was issued in mid-1972 for the now renamed mother-daughter mission. This was contrary to ESRO's standard procedure, because it had not yet approved the mission, but it was done to have time to incorporate this project into the International Magnetospheric Study 1976-1979 (IMS) for which ESRO was developing the GEOS (geostationary satellite), launched in 1977, and GEOS-2, launched in 1978.

Cooperation

The IMS was proposed as a concerted effort to acquire coordinated, ground-based balloon, rocket, and satellite data for enhanced understanding of the magnetosphere and its response to the solar wind. Many programs were begun worldwide in support of the IMS and coordinated through a central information exchange office. Information on satellite position was provided by the Satellite Situation Center at GSFC. As data became available, coordinated data analysis workshops were held with great success. The IMS helped stabilize the mission, which was finally named ISEE.

On ESRO's side, the ISEE mission was selected jointly with the x-ray mission HELOS, which was to be renamed European Space Agency's X-Ray Observatory (EXOSAT) in early 1973. After completion of a competitive Phase B in 1974, the contract for ISEE-2 was placed with Dornier Systems in late 1974. The joint launch of ISEE-1 and ISEE-2 in October 1977 occurred only 12 days later than had been predicted 3 years before.

ISEE was the first ESRO-NASA project in which hardware as well as software contributions were intimately intertwined. Thus, there was little experience with carrying out such an enterprise and determining the best organizational form. On either side of the Atlantic were a project manager and a project scientist (who were thought to represent and protect the rights of investigators). These four made up the JWG responsible for running the project. The PIs formed a science working team (SWT) that advised the JWG. The latter met every 3 months, the SWT twice a year. The MOU which covered these organizational relationships, laid down the general responsibilities of the two agencies.

Summary

There were probably three reasons ISEE became such an outstanding scientific success beyond the excellent technical work done by spacecraft contractors. First, at the time of the AO, integrated teams with the participation of scientists from several laboratories on either side of the Atlantic had formed and were seriously competing against each other. The teams were formed on the basis of mutual appreciation of similar or complementary expertise and often on already existing personal friendships. The established multiplicity of human ties proved to be a great help in problem solving and decision making in the SWT.

In addition, the two project managers for ISEE-1 and ISEE-2 (on which this discussion concentrates because of the symmetry between both sides of the Atlantic) were well suited for a cooperative project. Both leaders had strong personalities and a similar sense of humor; they respected each other and had a strong commitment to finding the most practical interfaces between their respective activities and products. They were equally and appropriately unimpressed sometimes by certain contradicting formal requirements. For example, they jointly opposed (successfully) the imposition of NASA specifications on European industrial contractors. A similarly harmonious relationship developed between project scientists at NASA and ESA. The value of people with a strong dedication to international cooperation, a commitment to solving problems, and a sense of humor should not be underestimated.

Finally, as mentioned above, the ISEE project was a fundamental (and probably the most important) element in the IMS. It was embedded in a highly motivated, worldwide activity. Coordinated ground-based observations and measurements of other satellites with ISEE were commonplace. The scientific community preparing for and subsequently working with ISEE data and producing supporting theories was steadily growing throughout the 1970s and early 1980s. A crisis in the project was hardly conceivable and never occurred. Altogether, ISEE is one of the outstanding examples of harmonious and successful transatlantic cooperation.

Lessons Learned

In space physics, a long-lasting tradition of cooperation between scientists from either side of the Atlantic, which accelerated with the availability of access to space starting in the 1960s and has continued ever since, created a solid foundation for successful international cooperation on the mission level. Although there was fierce competition in some cases (not necessarily between scientists on different continents), in general it did not result in protective actions with the aim of excluding the other side from participation in a particular mission. In most cases the advantages of cooperation were recognized clearly because the multiparameter nature of mission objectives made combining the individual expertise of various laboratories almost a necessity. Complete coverage of measurement parameters was more important than geographic balance or national pride.

A stabilizing factor was that mission ideas were often subjected to a competitive selection process during which cooperating teams formed even before an AO was issued for the proposal of science instrumentation. In the accompanying study phases, all scientific objectives and their experimental implementations were thoroughly analyzed. Hence, international teams and agreements on goals were being formulated long before formal MOUs were drafted between the respective agencies. The relatively modest size of many of the missions in space physics amplified this PI-collegial mission development and hence the possibility for successful international cooperation. This is particularly true in NASA-European national space agency cooperation as opposed to NASA-ESA cooperation.

As a consequence, it is no surprise that the problems that arose rarely originated from the group of individual scientists but from the agencies instead.

Small Scale and PI Based

AMPTE was basically a two-PI mission, one on each side of the Atlantic, but both responsible for the scientific objectives of the entire mission. In addition, they were responsible to their respective funding agencies for production of the hardware and proper use of the funds, as was the lead scientist for UKS. ISEE, although larger and with multiple PIs, still had the principal investigator in a central role.

ISEE and AMPTE were motivated by well-defined science goals. Principal control of the program was through PIs. This was particularly true of AMPTE, which was relatively small, but also of ISEE. At all stages of the program, science was the overriding issue. Individuals made all final decisions; these were not made by committees.

- AMPTE and ISEE were well served by a low-cost, easily accessible ground data system. Data distribution was simple.
- Minimization of international red tape helped significantly in the evolution of the design and the correction of some technical problems. National agencies did not overmanage the program. For example, the MOU for AMPTE was quite broad and flexible, allowing for changes late in the program.

Clean Lines of Authority and Excellent Communication

For AMPTE, since NASA was to provide the launch, the NASA project manager had the overall responsibility for flight worthiness of the three-spacecraft stack. The two European spacecraft were represented by a German project coordinator whose attention was focused on smooth interfaces across the Atlantic and on internal milestones and cash flow. On ISEE, excellent personal relations between the two project managers amplified the value of clean boundaries and minimized difficulties when they occurred.

- Simple interfaces (both in management and in engineering) were an important element of the success of AMPTE and ISEE.
- In the ISEE and AMPTE missions, there were excellent U.S.-European communications and rapport. There was great confidence in the reliability and competence of the partners. Excellent communication among engineers, scientists, and technicians within each national team, as well as between these teams, was the norm. Sharing technical (engineering and technology) information across the Atlantic was crucial to the success of AMPTE.
- There was a breakdown in communication in ISPM. Various parties in the cooperative process—scientists, agency officials, and congressional figures, for example—were not privy to critical information on mission status and budget. This was especially proven in the U.S. failure to consult Europe once budget pressures put ISPM in jeopardy. Europe's lack of understanding of the U.S. mission approval and budget process exacerbated misunderstandings.

Strong Joint Working Groups

In AMPTE, the two PIs headed the joint SWT, assisted by excellent project scientists for the representative satellites. All scientific goals, the approaches to their realization, the construction of scenarios for magnetospheric tracing experiments, the data-sharing policy, the command structure, and mutual consultations in the actual execution of plasma releases were jointly planned by the SWT. Many friendships developed in the course of the mission, which helped glue the teams together, not only on the level of participating scientists but also among many of the technical personnel. No wonder that free access to the data of any instrument by all participating investigators was easily agreed upon, while individual rights to data were respected. This basic structure and the fact that all of the spacecraft were developed and built in scientific institutions under the control of the respective PIs (or U.K. lead scientist) and their spacecraft managers created a stable atmosphere of mutual trust and technical assistance on all working levels.

In ISEE, there was an intensity of cooperation within smaller interdisciplinary teams that is rather remarkable and that contributed to its overall success.

Element of a Larger International Program

The ISEE project was a fundamental element and probably the single most important one in the International Magnetospheric Study 1976-1979. It was part of a highly motivated worldwide activity in which coordinated ground-based observations and measurements of other satellites with ISEE were commonplace. The value of this approach is seen elsewhere (e.g., with the Ocean Topography Experiment [TOPEX-POSEIDON] in the World Ocean Circulation Experiment).

The Budget Process: The "Good" News

On the U.S. side, AMPTE was accomplished by funding through the Explorer line item budget, which had a history of continuity. On the German side, the entire contribution was funded at the level of a typical scientific instrument, and funds were entirely within the control of the institute. Similarly, this Explorer-class aspect kept the ISEE within budget lines, kept development schedules short, and forced partners to adhere to schedules. (If ISPM had been an Explorer-class mission as well, it might not have encountered the budgetary problems that beset the mission.)

- The ISEE and AMPTE missions, once into the hardware phase, enjoyed stable sources of funds on both sides of the Atlantic.
- With AMPTE, NASA's help in purchasing key components for the European partner kept costs under control. Help with customs regulations was also useful to both sides.

At some stage, strong political connections stabilized the AMPTE program budget.

Budget Process: The "Bad" News

Cancellation of an international cooperative space mission is more likely in the United States than Europe. The ISPM experience highlights this possibility. The reasons for this are rooted in the existing budget and agency processes:

- The annual congressional review and approval of NASA's budget may result in the refusal to fund any program in any given year;
- NASA's funding priorities can change, especially with a change of administration;
- NASA's budget is more integrated than ESA's, so that if NASA's highest-priority program has serious budgetary difficulties, other NASA programs can be at risk. This is less likely in Europe, where the mandatory science program is not at risk if, for example, the Ariane launcher program should require additional funding; and
- If negative budgetary pressures are strong enough in Europe, cancellations could occur there as well. Thus, unilateral cancellation of an international program remains possible because there is no guaranteed protection against such an action being taken.

Warning Signs

Warning signs of dangers of cancellation of an ESA-NASA program are often interpreted differently by NASA and ESA. This appears to have been the case on ISPM. Communication is essential, and such warning signs must be heeded.

Role of the Memorandum of Understanding

The joint committee recognizes that the MOU is an imperfect process for cooperation and can hardly be the basis for international cooperation. However, it remains an important process and can be a crucial stabilizing factor. From the ISPM experience, certain lessons emerge:

- If a mission plan includes uncertain technical development issues, the MOU must explicitly address these elements and the associated risks. It must include provisions for unfulfilled technical expectations.
- MOUs are more easily implemented and followed if instrumentation and other engineering issues are in an advanced stage of development.
- An important element in any MOU should be the obligation for early consultation of partners in case of crisis. This is particularly important when unilateral action would harm the partnership.
- Cancellation or other significant perturbations in the ISEE and AMPTE programs were not avoided because of a better MOU. What was important to the successful completion of these missions was that the partners shared an "early warning system," a political networking that functioned better than in the case of ISPM.

Being International Does Not Ensure Support

The common belief that multinational missions will provide enhanced protection against cancellation is obviously invalid. Over the years there have been a number of cancellations; CRAF and ISPM are but two. For ISPM, there may be a lesson: Namely, it is not clear that full participation was necessary to achieve an important scientific contribution. Full participation would have provided additional science in ISPM, but significant science achievements might result from a one-spacecraft mission, as was proven eventually by Ulysses. This lack of essential and close coupling of both parties may have been a weakness in ISPM. It should be noted, of course, that the loss of the second spacecraft carried with it not only the loss of contemporaneous measurements of the other solar pole but, perhaps more importantly, the loss of the instruments (European and U.S.) that were canceled along with the U.S. spacecraft. It appears that the two spacecraft were far more coupled in the ISPM than in the Mars orbiting spacecraft discussed earlier (i.e., Kepler and Mars Observer), yet a similar fate was realized (one spacecraft was canceled while the other proceeded on the mission).

In the AMPTE and ISEE missions, loss of the scientific objective if one side canceled its contribution was more obvious (more real) than in the case of ISPM.

EARTH SCIENCES

There is a broad, multidimensional context that influences Earth observation missions and the characteristics and dynamics of international cooperation.

1. One aspect of this context is the myriad interests and objectives of Earth observation: scientific, operational, commercial, political, and military. The historical development of Earth remote sensing at NASA illustrates operational objectives. Aside from the operational meteorological satellites, it is clear that the early Earth observation satellites were "operations driven." The scientific community used the data without a predefined scientific program governing the observations actually achieved. The first Earth observation satellite that was "scientifically driven" and included a predefined scientific program was the Upper Atmosphere Research Satellite (UARS) launched in 1991.[53]

This multidimensional context continues today, when nonscientific reasons may provide significant impetus for Earth observation missions. Moreover, these various interests can confuse the process of defining the goals of an international cooperative mission. The importance of the operational and practical applications of Earth observation data has led governments and agencies to create international coordination mechanisms such as the Coordination Group for Meteorological Satellites, the Committee on Earth Observation Satellites (CEOS), and the

[53] Even in naming the mission, it was considered necessary to use the word "research."

Earth Observation-International Coordination Working Group (EO-ICWG). Overall, however, Earth observation for Earth sciences remains an emerging process.

From the opposite perspective, the set of data acquired from a given NASA, ESA, or European Earth observation mission may used for several different purposes. For example, data from meteorological satellites can be used for scientific as well as operational purposes; data sets from scientific satellites have operational, commercial, and military uses. These secondary beneficiaries of Earth observation data can lead to restrictions on how the data are used. Consequently, policies on data use in Earth science are extremely important and often difficult to implement. Differences in establishing these policies continue to affect international cooperation in Earth science.

2. In a similar vein, the development of more technologically advanced observing instruments and more efficient algorithms to extract useful information from the observations can have commercial and industrial benefits as well as scientific advantages. This "technology push" can introduce conflicts of interest in existing or planned international cooperation where none previously existed.

3. In addition, Earth science disciplines vary widely and have different antecedents: atmospheric sciences (physics, [bio]chemistry); oceanography (physics, chemistry, biology); and land surface studies (hydrology, plant physiology, agronomy, soil sciences, geology, ecology, geography, etc.). There is hardly a single Earth science community.[54] The use of space observations in these disciplines and their level of sophistication in terms of modeling differ in part because of the intrinsic emphases of the disciplines, which reflect differences in the underlying processes themselves. For instance, models of the ocean and atmosphere are based to a certain extent on the application of basic hydrodynamic equations, whereas a corresponding basis for analysis of the terrestrial system is not available. The requirements for observations, even of the same variable, vary by discipline and therefore can easily change over time. This can appear confusing or redundant when, in fact, it is neither.

4. Unlike some of the space sciences, there is a wealth of data in the Earth sciences at spatial and temporal scales far finer than the pixel scales of the remotely sensed data from space science research. This allows and demands a suite of important associated activities—field programs, validation campaigns, calibration experiments, and assimilation efforts—to blend data types. Such experiments lead to particular types of international cooperation as well as a set of external schedules and requirements, often with an international flavor, that must be met by the space-based program.

To probe certain Earth phenomena such as the climate system, relatively long-term observations are necessary. Yet measurements with different spatial and shorter temporal resolutions are necessary to examine other types of problems. Often, however, the same geophysical quantity (or a similar one) is of interest. The myriad interests and data needs of a particular geophysical property can therefore lead to conflict in determining the requirements for an Earth observation mission. Furthermore, serving these multiple interests can necessitate the collection of huge data sets by a variety of international agencies.

5. Finally, for some of the space agencies, Earth science and space science programs follow different processes for mission definition, approval, and financing. ESA is a case in point: Earth observation is an optional program, whereas the ESA space science program is mandatory, with secured funding. At the same time, the European Union has a much greater interest in Earth observation than in space science disciplines because of its potential applications.

The Case for Cooperation

There are strong reasons for international cooperation in Earth science missions. The nature of Earth-observing satellites leads almost automatically to international cooperation and data sharing, because the space-

[54] However, there is an increasing recognition of the interactions between different Earth science fields as well as an awareness of the importance, for instance, of coupling models of the atmosphere to models of the ocean and land.

based observations are inherently global. Associated with this shared observation, the history of data exchange within Earth sciences spans more than a century: International data exchange has existed since the earliest days of the space program, often within the framework of preexisting agreements for environmental data exchange. Many of the scientific spacecraft systems have been justified partly on the basis of contributions to international programs (e.g., the Global Atmospheric Research Program [GARP] or the World Ocean Circulation Experiment [WOCE]). The international scientific community has therefore been involved from the beginning in setting the goals of space missions in Earth observation.

There are at least three types of space-based international cooperation in Earth science:

1. Missions designed with scientific objectives defined in an international cooperation (e.g., TOPEX-POSEIDON, UARS);
2. International data exchanges for scientific purposes in which the hardware is essentially produced on one side of the Atlantic (e.g., the European Remote Sensing Satellite [ERS] and the upcoming Earth Observing System [EOS] from NASA and the Environmental Satellite [ENVISAT] from ESA); and
3. Missions with operational or commercial objectives (e.g., the National Oceanic and Atmospheric Administration [NOAA] spacecraft, the European Geostationary Meteorological Satellite [METEOSAT] and the Geostationary Operational Environmental Satellite [GOES] or the Système Pour l'Observation de la Terre [SPOT] satellite).

It is worth noting that there are no NASA-ESA missions or cooperative activities in Earth science (despite an initial major effort with EOS and ENVISAT) and only a few U.S.-European bilateral missions—NASA with one (TOPEX-POSEIDON) or two (UARS) European nations. As there are lessons to be learned from such bilateral and trilateral cooperation, the lack of NASA-ESA multilateral cooperation may have something to impart as well.

Case Mission Choice and Rationale

Two missions and the polar platform activities have been chosen as cooperative examples for this study.

UARS is the first Earth observing mission based on a scientific program that was conceived and executed through international cooperation among four countries, namely the United States, the United Kingdom, and France, along with Canada. The hardware was designed to meet scientific requirements and was provided by each of the participating countries; data were shared more broadly.

TOPEX-POSEIDON is an example of a space mission that was jointly conceived and funded by the United States and France to contribute to solving a well-identified scientific problem. Elements of the mission (including hardware) were provided on both sides, and data were shared with the wider scientific community.

The polar platform venture is an example of an ambitious joint NASA-ESA program, combining scientific and operational applications. It was proposed at the agency level, in part to create a more efficient global monitoring system with the corresponding data distribution program. Although this joint activity did not come to fruition, it provided an important prelude to the current cooperative activity between NOAA and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) on the future EUMETSAT-Meteorological Operational Satellite (METOP) and the NOAA-DOD polar orbiting satellites.

The history of meteorological missions might have been considered here, but this study has limited its review to the science side of the issue.[55] Cooperation on meteorological satellites presents at least two additional interesting aspects, namely, data sharing and sharing of the satellites themselves. The topic of international cooperation for operational purposes is a rich and important one and merits further study.[56]

[55] Although these are not strictly scientific missions, the data they provide are very useful to the scientific community.
[56] The issue of convergence will make this topic even more important in the future.

Upper Atmosphere Research Satellite

Introduction

The mid-1970s were exciting times in stratospheric research. The furor over the potential impact of the Supersonic Transport (SST) aircraft on the ozone layer was fading when a newly noted chemical reaction involving chlorine and ozone became the subject of focus in scientific journals. It was proposed that chlorofluorocarbons (e.g., CFC-11, CFC-12), otherwise known as Freon® and previously assumed inert, would eventually drift up to the stratosphere, photolyze by UV radiation, and release chlorine. When the chlorine was subsequently oxidized to chlorine monoxide (ClO), it would destroy ozone at a rate much faster than molecules such as nitrogen oxides (NO_x), the product of SSTs. The scientific community was challenged to study the impact of CFCs on the stratosphere, project the loss of ozone, and assess the impact of the transmission of biologically harmful UV radiation to Earth's surface.

NASA had a problem of its own. It was suggested that emission gases from Shuttle launches, which contained chlorine, would aggravate ozone loss in the stratosphere. This subject was hotly debated by NASA advisory committees, within NASA itself, and at several boards and committees of the U.S. National Academy of Sciences. It became clear that because there would be only a few Shuttle launches (one or two per month), their effect on ozone destruction would be minimal compared with that of CFCs. But the debate continued on the magnitude and spatial distribution of ozone loss over time that would result from the buildup of CFCs. Although stratospheric research models were being effectively developed, data on the chemistry and dynamics of the stratosphere that could be used to check these models were almost nonexistent.

Historical Background

Scientists inside and outside NASA began to push the agency to launch a comprehensive mission to study the linked physical and chemical dynamics of the stratosphere. The conjuncture was just right. Scientists who had been involved with NASA's program on planetary exploration were ready and available to work on research related to Earth's stratosphere. Similarly, stratospheric scientists could benefit from instruments being prepared for launch on Pioneer Venus to study its stratosphere, which provided an excellent heritage of scientific knowledge.

NASA's Office of Space Science and Applications (OSSA) set up a Stratospheric Science Advisory Committee to define a mission that would address the fundamentals of stratospheric science rather than just measure chlorine, NO_x, and ozone. U.S. and European stratospheric scientists had been working together over the years, so NASA invited the Europeans to join the committee. The mission was extraordinarily well conceived scientifically.

Cooperation

UARS was launched in September 1991. The observatory, 10 m long and more than 6 metric tons, carried nine large scientific instruments: seven from the United States, one from the United Kingdom, and one from a Canadian-French consortium. The success of the mission became clear as precise measurements were made not only of ozone but also of molecules that play critical roles in ozone chemistry, such as ClO, NO_x, and nitric acid (HNO_3). To understand the physics, radiation measurements were carried out to great precision, while the study of middle-atmosphere temperature and dynamics got a big boost from using measurements made by a variety of instruments.

An important feature of this mission was its science team, which included 9 instrument PIs, 12 theoretical and collaborative PIs, and an interdisciplinary team leader. Each member had instant access to the data of other investigators and, as such, could look collectively at the stratosphere in evolution. By pooling talent on both sides of the Atlantic, the mission provided data and insights that enabled the scientific community to discard theories that did not support the data. At the same time, the cooperative effort vastly improved knowledge of the physical and chemical processes occurring in the stratosphere.

The UARS mission is innovative both in the comprehensive and unique data set it has provided and for some of the organizational procedures it has implemented. The UARS science team includes a wide range of PIs, theoretical and collaborative investigators, and guest observers.[57] UARS data are processed at the Central Data Handling Facility using software provided and maintained by the science team. These data are available to the scientific community through the GSFC Distributed Active Archive Center.[58]

In addition to data from UARS instruments, meteorological data from the U.S. National Meteorological Center and the U.K. Meteorological Office are included in the UARS Central Data Handling Facility. These meteorological data have been extremely valuable both for processing UARS instrument data and for scientific analyses.

Data validation has been an essential part of the UARS program. A comprehensive correlative measurements program, involving ground-based, aircraft, and balloon instruments, has been integral to UARS. Several international validation workshops were held following the UARS launch and before data were first publicly released to the scientific community. This was done to ensure that the data were adequately understood and documented before their general use in scientific analyses. These workshops considered the internal consistencies of individual UARS data sets, comparisons among UARS instruments measuring the same parameters, and comparisons with data from the UARS correlative measurements program and with data from other satellites. These cross-calibrations and data inspections generally have been a hallmark of the UARS international team.

In 1997, UARS continued to provide valuable data far beyond its primary goal of observing two Northern Hemisphere winters. Five northern winters have been observed to date, and 8 of the 9 mission instruments continue to operate (Cryogenic Limb Array Etalon Spectrometer [CLAES] measurements stopped in April 1993 after the cryogen was depleted, and Improved Stratospheric and Mesospheric Sounder [ISAMS] measurements stopped in July 1992 after the chopper failed).[59] The observatory is currently being operated in a reduced-power mode with time sharing of instrument observations.

Summary

UARS was planned with the involvement of European scientists and has included investigators from several European countries and instruments from Britain, France, and Canada. The data were analyzed jointly by teams of scientists and guest investigators from both sides of the Atlantic. The extensive array of papers being published in peer-reviewed journals attest to the high quality of science the mission has produced. This was made possible by two hitherto unique arrangements that were enacted to enhance the teamwork. First, data systems were organized so that each instrument team member had access to other instruments' data products, which enabled scientists to make diagnostic checks on their findings. In addition, before papers were sent out for publication, they were refereed and reviewed by the entire science team. As a result, the very first set of papers published on the results of UARS still remain standard references in stratospheric science.[60]

Ocean Topography Experiment (TOPEX-POSEIDON)

Introduction

The Ocean Topography Experiment (TOPEX-POSEIDON) is a cooperative project between the United States and France to develop and operate an advanced satellite system dedicated to observing Earth's oceans. The

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57 The UARS science team has recently been augmented by about 60 guest investigators.

58 <http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/UARS_project.html>

59 Microwave Limb Sounder [MLS] stratospheric water vapor measurements stopped after April 1993 following failure of the 183-GHz radiometer (MLS continues measurements of ozone, ClO, temperature, HNO_3, and upper tropospheric water).

60 UARS mission and instrumentation papers in *J. Geophys. Res*. 98(D6), June 20, 1993; Reber, C.A., et al., "The Upper Atmosphere Research Satellite (UARS) Mission," *J. Geophys. Res.* 98:10643-10647, 1993.

mission provides global sea-level measurements with unprecedented accuracy. Data from TOPEX-POSEIDON are used to help determine global ocean circulation and understand how the oceans interact with the atmosphere. This understanding is essential to improving the understanding of global climate and other aspects of global environmental variability and change.

For this joint mission, NASA provided the satellite bus and five instruments with their associated ground elements. JPL has been responsible for project management; it operates and controls the satellite through NASA's Tracking and Data Relay Satellite System. France's Centre Nationale d'Études Spatiales (CNES) furnished two instruments with their associated ground elements and provided a dedicated Ariane launch. Both CNES and NASA provide precision orbit determination and jointly process and distribute data to 38 science investigators from 9 nations, as well as other interested scientists. The management approach for this mission included two program managers, two project managers (for their respective share of the project), and two project scientists (co-chairing the TOPEX-POSEIDON Science Working Group) who share in the selection of PIs for calibration and validation of the data and for data evaluation and analysis.

Historical Background and Cooperation

In February 1980, NASA established a TOPEX Science Working Group to consider the scientific usefulness of satellite measurements of ocean topography, especially for the study of ocean circulation. A report of the group's findings was published in March 1981.[61] At the same time, a group of French scientists studied essentially the same topics and proposed the POSEIDON mission in a report of its findings to CNES in October 1983.[62] The primary finding of the two groups was that satellite altimeter observations of ocean topography can provide the global information on ocean dynamics necessary for studying many important oceanographic problems.[63]

During the following years, NASA and CNES refined the requirements for an altimetric satellite mission and studied the feasibility of a joint mission. These studies resulted in an MOU that was drafted by the NASA-CNES study team and approved by both organizations. It covered programmatic and scientific subjects and is widely regarded as the agreement that put the mission on the path to success. French scientists persuaded the director general of CNES to help their U.S. colleagues convince the NASA administrator that TOPEX-POSEIDON would make an important contribution to oceanography. In return, U.S. scientists and NASA managers kept the momentum going when TOPEX-POSEIDON faced financial difficulties during changes of administration in the French government.[64]

The initial success of the cooperation was also enhanced by the strong interest in altimetry that both sides had developed. They were able to contribute significantly in required areas of expertise such as oceanography, altimetry, orbit calculations, and satellite technology. Yet national pride and their advanced status in altimetry made some participants reluctant to cooperate and share their technical knowledge. Some managers did not want to relinquish a perceived technical lead to other countries. Furthermore, an Ariane launch was not acceptable to NASA for political and scientific reasons (NASA wanted to see the Space Shuttle used for the launch, believing that carrying out altimetry from a SPOT spacecraft bus with its Sun-synchronous orbit would introduce error into certain tidal measurements). Eventually agreement was reached to use an Ariane launch with the bus provided by the United States.[65]

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[61] TOPEX Science Working Group, *Satellite Altimetric Measurements of the Ocean*, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, Calif., March 1981.

[62] Centre National D'Études Spatiales, *POSEIDON*, CNES, Toulouse, France, October 1983; interview with Michel Lefebvre, formerly with CNES, Toulouse, September 22, 1996.

[63] Interview with Stanley Wilson, Assistant Administrator, National Oceanic and Atmospheric Administration, Washington, D.C., April 12, 1996.

[64] Interview with Charles Yamarone, Jet Propulsion Laboratory, TOPEX-POSEIDON project manager at Pasadena, Calif., March 18, 1996; interview with Chester Koblinsky, NASA/Goddard Space Flight Center, Beltsville, Md., head, Oceans and Ice Branch, March 20, 1996.

[65] See footnote 64.

In the summer of 1992, TOPEX-POSEIDON was launched into orbit by an Ariane rocket from ESA's Guiana Center for Space in Kourou, French Guiana. From its orbit 1,336 km (830 miles) above Earth's surface, TOPEX-POSEIDON makes sea-level measurements along the same path every 10 days using the dual-frequency altimeter developed by NASA and the CNES single-frequency solid-state altimeter. This information is used to relate changes in ocean currents to atmospheric and climate patterns. Measurements from NASA's microwave radiometer provide estimates of the total water vapor content in the atmosphere, which is used to correct errors in altimeter measurements. These combined measurements allow scientists to chart the height of the seas across ocean basins within an accuracy of about 5 cm.

Three independent techniques determine the satellite altitude. NASA's laser retroreflector array is used with a network of 10 to 15 satellite laser ranging stations to provide baseline tracking data for precision orbit determination and calibration of the radar altimeter bias. The Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) system, demonstrated by the French SPOT-2 mission, provides an alternate set of tracking data using microwave Doppler techniques. The system is composed of an onboard receiver and a network of 40 to 50 ground transmitting stations, providing all-weather global tracking of the satellite. NASA's Global Positioning System demonstration receiver provides a new technique for precise, continuous tracking of the spacecraft.

Summary

One reason TOPEX-POSEIDON became a scientific and cooperative success was that it originated at the grassroots of the scientific community and involved many key scientists on both sides in a careful planning effort. Some team meetings were attended by as many as 250 scientists; this breadth enhanced the team's creativity. Detailed mission planning took about 2 to 3 years. Delays in a new start in the United States were translated into time for improved mission definition.

The MOU for TOPEX-POSEIDON was a significant agreement between CNES and NASA. The up-front planning and specific joint management teaming between international partners led to the signing of an effective MOU between NASA and CNES and their success in implementing the TOPEX-POSEIDON mission. It was drafted by a joint study team over several years and was reviewed and approved by NASA and CNES after lengthy and constructive debate. It clearly covered both programmatic and scientific subjects and constituted a major cornerstone for French-U.S. scientific cooperation.

Though the MOU coordination on science AOs was spelled out in sufficient detail, which was important to mission success, the MOU and other original agreements did not specifically outline how altimetry data were to be shared and what calibration information was to be provided. As a result, there were occasional problems with using one another's data because of the lack of engineering and calibration information provided by other team members. (Some U.S. scientists have stated that even now they do not understand the details of the French altimetry system.)

During the development phase, both CNES and NASA had events that required increased resources and considerable risk taking. A joint steering group dealt with such situations effectively.

Another important element in this cooperative effort was the level of cost sharing. CNES agreed to cover about 30 percent of the total cost of the project, including the launch, a 13.6-GHz altimeter (in addition to NASA's dual-frequency instrument operating at 13.6 and 5.3 GHz), and the DORIS microwave Doppler tracking system, which had proven successful on the French SPOT-2 mission. One estimate claims that the internationalization of TOPEX-POSEIDON saved the United States at least $250 million.[66]

Data sharing, other than the details on altimetry and calibration data, was ensured not only by the MOU and other agreements but also by the fact that TOPEX-POSEIDON is a vital part of an international research effort to explore ocean circulation and its interaction with the atmosphere. The mission was timed to coincide with and complement a number of international oceanographic and meteorological research efforts, including WOCE and

[66] Interview with Charles Yamarone, Jet Propulsion Laboratory, TOPEX-POSEIDON project manager at Pasadena, Calif., March 18, 1996; interview with Chester Koblinsky, NASA/GSFC, Beltsville, Md., head, Oceans and Ice Branch, March 20, 1996.

the Tropical Ocean and Global Atmosphere (TOGA) program, both of which are sponsored by the World Climate Research Program. TOPEX-POSEIDON completed its 3-year mission and is currently in an extended observation phase; a joint NASA-CNES follow-on mission, Jason-1, is planned for 2000. Results from TOPEX-POSEIDON are building the foundation for a continuing program of long-term observations of ocean circulation from space and for an extensive ocean monitoring program in the next century.

Earth Observing System

Introduction

During the early 1980s, interest in Earth observation from space was growing rapidly, thanks to the successful operations of Landsat and NOAA satellites, METEOSAT, the future programs of ERS and SPOT in Europe, and the programs prepared cooperatively between the United States and European countries (i.e., UARS and TOPEX-POSEIDON, discussed above).[67] At the time, the United States was engaged in the design of a Space Station, which included a human-tended polar orbiting platform along with a co-orbiting science platform. This was an infrastructure-driven, all-embracing approach that assumed big, serviceable polar platforms for scientific and operational purposes.

NASA's Earth science program took advantage of the polar orbiting platform for its design of a global Earth observation system. Following President Reagan's decision to build a Space Station, the United States invited Europe to participate. ESA accepted this invitation, which fit with its new approach for Earth observation:

- Multidisciplinary payloads;
- In-orbit intervention for servicing, repair, and addition of new payloads;
- Contribution to and shared use of the new capability of the Earth observation system by different nations; and
- Combination of operational, experimental, and research instruments.

This approach also interested the operational agencies. The convergence of interests led the concerned agencies to join in building a system that could meet their objectives by improving the monitoring capabilities of space systems and by reducing their own financial contribution through cost sharing. Thus the concept of permanent polar platforms for international global Earth observation was born.[68]

Historical Background

In the United States, the case for an Earth observing system based on a set of polar platforms emerged in the early to mid-1980s, when scientists and engineers created a new perspective on how to conduct future NASA Earth-observation programs. Three studies—known as the Goody, Friedman, and Bretherton reports, and issued by NASA, NRC, and the Earth System Sciences Committee, respectively—were pivotal in developing the new vision[69] leading

[67] Space Studies Board, National Research Council, *Earth Observations from Space: History, Promise, and Reality*, National Academy Press, Washington, D.C., 1995.

[68] Quoted from N. de Villiers, Working Group on Earth Observation Requirements for the Polar Orbiting Platform Elements of the International Space Station, ESA-SP 266, ESPOIR, November 1986.

[69] Report of a NASA workshop, *Global Change: Impacts on Habitability*, *A Scientific Basis for Assessment*, chaired by Richard Goody at Woods Hole, Mass., June 21-26, 1982, submitted on behalf of the Executive Committee, July 7, 1982 (Jet Propulsion Laboratory, Pasadena, Calif., 1982); report of a National Research Council workshop, *Toward an International Geosphere-Biosphere Program*: *A Study of Global Change*, chaired by Herbert Friedman at Woods Hole, Mass., July 25-29, 1983 (National Academy Press, Washington, D.C., 1983); reports of the Earth System Sciences Committee chaired by Francis Bretherton: Earth System Sciences Committee, NASA Advisory Council, *Earth System Science Overview: A Program for Global Change*, NASA, Washington, D.C., 1986; Earth System Sciences Committee, NASA Advisory Council, *Earth System Sciences: A Closer View*, NASA, Washington, D.C., 1988.

to the so-called Mission to Planet Earth (MTPE) program and provided the foundations upon which MTPE was built. (MTPE has been renamed the Earth Science Enterprise at NASA.) The early discussions within the science and engineering communities began to have a strong influence on federal programs well in advance of the formal publication of these reports. NASA published a two-part report in 1984[70] and another report in 1987[71] that included a series of volumes describing the principal instrument concepts and associated investigations.

At the same time, the NRC Space Science Board (as of 1989, Space Studies Board) continued its work and published a series of strategy and assessment documents.[72] The latest report, while offering suggestions for improvement, endorsed the overall concept of the MTPE and urged (as previous reports had) that the intermediate-class platforms of the Earth Observing System (EOS) be complemented by an expanded set of smaller satellites.

Similarly, in Europe, there were several agency initiatives to prepare a contribution to this polar platform system. Beginning in 1983, ESA had undertaken a series of three studies, known as European Utilization Aspects (EUA) studies, under a contract with the German aerospace research establishment, DLR, to define the European platform. This first approach was the responsibility of industries. Scientific communities and future users would be involved only as providers of potential applications; therefore, the resulting propositions were not based on a well-defined and coordinated scientific program.[73] This European effort was undertaken with the United States. A first joint utilization workshop was held at Woods Hole, Massachusetts, in 1984. Then, to finalize scenarios prepared on both sides of the Atlantic, an ESA-NASA-NOAA group was set up, and an extensive joint effort between ESA and NASA was organized.

After the first three studies, ESA—assisted by a working group of experts, the Earth Observation Advisory Committee (EOAC, established in 1981)—initiated a study to outline Earth observation requirements for the Polar Orbiting Platform Element (POPE). For the purpose of this study, the scientific community was directly involved through EOAC with representatives of the EUA study group. The study produced a scenario with two serviceable polar platforms (a morning one under ESA's aegis and an afternoon one under NASA's) that would accommodate a combination of operational, experimental, and research instruments. Following this first definition, in June 1986, ESA invited about 80 scientists from all ESA member states to a workshop, the European Symposium on Polar Platform Opportunities and Instrumentation for Remote Sensing (ESPOIR). The agency aimed to develop a consensus of the Earth observation scientific and applications user community on the requirements, priorities, and content of missions to be flown on the polar platforms.[74] This preparation was going on in parallel with development of the ERS-1, which focused on ocean and ice application because of the strong commitment of the oceanic scientific community, and with the work of the International Polar Orbiting Meteorological Satellite (IPOMS) working group, which was focusing on atmospheric applications. The Earth science community also held a preparatory meeting under ESA's sponsorship in March 1986 to review the objectives and requirements of the land science community.[75] (The atmospheric and ocean science communities, which already had missions planned, were better prepared than the land science communities to respond to these studies.)

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70 National Aeronautics and Space Administration, *Earth Observing System, Science and Mission Requirements Working Group Report,* vol. I, parts 1 and 2 (NASA Technical Memorandum 86129), Goddard Space Flight Center, Greenbelt, Md., 1984.

71 National Aeronautics and Space Administration, *From Pattern to Process: The Strategy of the Earth Observing System, EOS Science Steering Committee Report,* vol. II, NASA, Washington, D.C., 1987.

72 Committee on Earth Sciences, Space Science Board, National Research Council (NRC), *A Strategy for Earth Science from Space in the 1980s—Part I: Solid Earth and Oceans*, National Academy Press, Washington, D.C., 1982; Committee on Earth Sciences, Space Science Board, NRC, *A Strategy for Earth Science from Space in the 1980s and 1990s—Part II: Atmosphere and Interactions with the Solid Earth, Oceans, and Biota,* National Academy Press, Washington, D.C., 1985; Task Group on Earth Sciences, Space Science Board, NRC, 1988, *Space Science in the Twenty-First Century* (7 vols.), National Academy Press, Washington, D.C., 1988; Committee on Earth Sciences, Space Studies Board, NRC, *Strategy for Earth Explorers in Global Earth Sciences,* National Academy Press, Washington, D.C., 1989; Space Studies Board, NRC, *Space Studies Board Position on the NASA Earth Observation System,* National Academy Press, Washington, D.C., 1991; and Committee on Earth Studies, Space Studies Board, NRC, *Assessment of Satellite Earth Observation Programs*, National Academy Press, Washington, D.C., 1991.

73 The International Land Surface Climatology Project (ILSCP) was established under the leadership of S.I. Rassol and H.J. Bolle in 1983 and included U.S.-European cooperation in field experiments.

74 Duchossois, G., ESPOIR— ESA Workshop, Avignon, France, June 16-18, 1986 (ESA SP-266), November 1986.

75 SESAME (ESA-SP 1080), 1986.

The coordination efforts of ESA, NASA, and NOAA were aimed at defining the principles, content, and possible schedule for this international cooperative endeavor, particularly for preparing closely coordinated AOs by NASA and ESA. These AOs, with NOAA's and EUMETSAT's cooperation, were published in 1988 and included a description of the types of instruments that were to be on board the two platforms:

- Operational instruments provided and/or operated by governmental entities (e.g., meteorological sensors flown on NOAA's TIROS-N series) and possibly by commercial entities (i.e., Landsat TM-type sensor operated by the Earth Observing Satellite Company [EOSAT] in the United States, or the SPOT High Resolution Visible (HRV)-type sensor operated by SPOT-Image in France);
- Medium-size to large instruments; multipurpose core facilities, which were candidates to be provided by the Space Station partners, such as a high-resolution imaging spectrometer, multifrequency synthetic aperture radar, and high-resolution thermal infrared imager; and
- Small- to medium-size experimental instruments (noncore instruments), which could be provided nationally through the AO.

A list of more than 30 potential instruments was proposed.

In parallel with these efforts, the serviceable, large polar platform concept began suffering a series of setbacks. In 1986 *Challenger* forced many NASA programs to non-Shuttle launch designs. The co-orbiting (and hence the polar-orbiting) Space Station platforms were abandoned, leaving NASA's then Earth Science and Applications Division with the momentum of large polar platforms (one from ESA and one from NASA), but without the actual platforms. By this time, however, the move toward a global Earth-observing system was well under way. In the early 1990s, the planned scenario with two large polar platforms began to be seriously questioned both in the United States and Europe. In the United States, the committee conducting the EOS review recommended that the large polar platform be redesigned—specifically, that the size be reduced from a Titan IV-class launcher to an Atlas 2A class (later to a Delta-1 class platform) to complement these intermediate-size platforms with a larger number of smaller satellites. Furthermore, for budgetary reasons, program costs had to be cut.[76] A revised version of MTPE was proposed and approved by Congress in 1992 and included a separation of the operational instruments from the U.S. polar platform. Similarly, in Europe, ESA and the scientific community proposed replacing the polar platform (so-called POEM-1) with two satellites, namely METOP and ENVISAT. This had been recommended by the ESF/ESSC[77] and approved by the ESA Ministerial Conference at Granada in 1992. The polar platform venture was thus reduced to a descoped set of platforms and smaller spacecraft on the U.S. side (including EOS-AM1, EOS-PM1, and EOS-Chemistry 1) and ENVISAT on the European side. In Europe, the operational part of the instruments were to be placed on METOP, and in the United States, the operational instruments would be flown by NOAA on separate operational spacecraft.

Although scientific partnerships between U.S. and European scientists continued to grow, the only NASA-ESA cooperation left was reduced to the two instruments, the Clouds and Earth's Radiant Energy System (CERES) from the United States and the Multifrequency Imaging Microwave Radiometer (MIMR) from Europe, which were planned to be flown on both the U.S. and European satellites. However, neither NASA (mainly for financial reasons) nor ESA (mainly for managerial and programmatic reasons) was able to finalize cooperation on these two instruments. As a result, CERES was removed from ENVISAT and MIMR from EOS-PM1 (and even from ENVISAT and/or METOP). Unfortunately, these decisions were made without much consultation.

Ultimately, the cooperative polar platform venture proved too large a step to take, given the size and complexity of the program, the lack of previous experience in U.S.-European land-observing missions, and the emergent state of the interdisciplinary Earth system science approach. Despite the end of this particular NASA-ESA

[76] Moore, B., et al., "The Restructured Earth Observing System: Instrument Recommendations," *EOS, Transactions, American Geophysical Union*, 72(46):505, 510, 516, 1991; EOS Payload Advisory Panel, *Adapting the Earth Observing System to the Projected $8 Billion Budget: Recommendations from the EOS Investigators,* Berrien Moore III and Jeff Dozier, eds., NASA, Washington, D.C., 1992; Frieman, E., ed., *Report of Earth Observing System Engineering Review Committee*, NASA, Washington, D.C., 1991.

[77] EEOP-European Space Science Committee, European Science Foundation, *A Strategy for Earth Observation from Space*, ESF, Strasbourg, France, September 1992.

cooperative effort, work on the polar platform venture brought to fruition many successful U.S.-European activities on instrument and science teams and paved the way for a smaller joint activity on the three polar meteorological satellites: The METOP satellite from EUMETSAT will be coordinated with two National Polar-Orbiting Operational Environmental Satellite System (NPOESS) satellites, which are managed by a joint Department of Defense–NOAA program in the United States. Many in the Earth sciences community hope that the cooperation can be continued, at least through an appropriate data policy that allows for data exchange and sharing of scientific research.

Cooperation

Cooperation on the polar platforms took mainly a top-down approach, initiated by the agencies. Although many scientists supported the venture, the concept did not have the benefit of good coordination between the scientific communities in the United States and Europe. These communities did not enjoy the same status in their preparation of the platforms and worked independently in each country. In Europe, scientists were used as consultants and were not a driving force in the system. This appears in the asymmetrical objectives of the two AOs.

On the European side, the objectives were as follows:

- To determine the level of European interest in potential core instruments to be developed by ESA;
- To provide priorities for European use of different instruments within the payload;
- To identify AOs for instruments supported by ESA member states; and
- To identify possible investigations in the various disciplines, as well as interdisciplinary investigations (selection of PIs).

On the U.S. side, the AO had the following objectives:

- To identify scientific team members and leaders for facility or core instruments to be developed and funded by NASA;
- To identify a set of interdisciplinary investigations;
- To identify proposals for non-core instruments for further Phase B studies, which were ultimately to be confirmed for Phase C/D; and
- To provide guidance for the development of the Earth Observing System Data and Information System (EOSDIS).

Thus, the objectives of U.S. and European science differed, as noted in the dissimilar AO definitions; no joint research programs were proposed, and, at the scientific core of the program, the two communities diverged. This lack of coherence and organization between the two communities made it difficult to lobby decision makers when both the European agencies and NASA faced budget cuts and when financial difficulties arose in the polar platform venture. It was also difficult for NASA and ESA to agree on the necessary descoping of the platform; as a result, cooperation could not result in cost savings. In addition, Earth system science was a new interdisciplinary approach that some scientists took less seriously than traditional disciplines. The structure and hierarchy of the Earth system science program were less familiar, creating additional difficulties for scientists who were working through channels to seek support.[78] Finally, there was no agreement on data sharing and distribution; each agency had its own data policy. This remains a point of contention between NASA and ESA.

[78] It is interesting to note that the atmospheric, oceanographic, Earth science, and land subdisciplines of the Earth scientific communities on both sides of the Atlantic did not share the same attitude during this period. The atmospheric community was preparing the UARS mission discussed above, along with an analysis of Advanced Very High Resolution Radiometer (AVHRR), Geostationary Operational Environmental Satellite (GOES), and METEOSAT data. The oceanographic communities in the United States and France were preparing TOPEX-POSEIDON, discussed above; and the oceanographic European community with several U.S. universities took an interest in preparation of the European Remote Sensing Satellite (ERS-1), leading between 1981 and 1983 to a modification of its orbit (a higher orbit better suited for mesoscale circulation measurements by TOPEX-POSEIDON) and of its payload (inclusion of a K_u [12 to 18 GHz] radar altimeter and a precise positioning system, still complementing TOPEX-POSEIDON). Nothing equivalent occurred in the land science communities, which had no specific joint missions being prepared on the European side.

However, a substantial data exchange and agreement took place among ESA, NASA, and NOAA on the ERS-1. In addition, there was an MOU with NASA to receive data at the Fairbanks ground station; an MOU with NOAA for delivery of ERS-1 Low Bit Rate Fast Delivery products to NOAA for forecasting purposes; and collaboration between the United States and Europe on calibration and validation of ERS-1 instruments and data.[79]

Summary

The history and circumstances leading up to the failure of cooperation on NASA-ESA polar platforms involved many perspectives and interests. There is no simple answer as to why the cooperation unraveled; myriad factors and influences contributed to the unsuccessful result. The beginnings of the polar platforms and Earth Observing System had its roots in the large Space Station program. In promoting the Space Station, the United States attempted to link the polar platforms and Earth observation in general, through a so-called intergovernmental agreement. This top-down approach assumed serviceable platforms for scientific and operational uses and a unified Earth observation data policy discussed under EO-ICWG and CEOS. Moreover, the programmatic decision to use large polar platforms introduced a new, unaffordable approach for Earth observation programs.

Within the space community, scientists supported this approach, not always for scientific reasons, but because they initially were given a platform on a "take-it-or-leave-it" basis. Once work on the program began, the Earth science communities were not well coordinated and not accustomed to working together. There was an inadequate historical basis for joint space-based scientific research on both sides of the Atlantic, at least in land science. The scientific communities in Europe and the United States had different levels of preparation and involvement in defining the polar program. This imbalance created a dissymetry in the relationships among the program managers.

In addition, the conception of the program itself changed early on, as did the context in which the program was conceived. The aftermath of *Challenger* created uncertainty for all launches; preparation for other missions in ocean and atmospheric sciences led to a variety of motivations among scientific users, as well as a difference in levels of preparation. The fact that the mission's objectives were not focused on a well-defined goal made scientific users unwilling to lobby for it. Furthermore, both Europe and NASA faced budget cuts, had (and still have) difficulties preserving their respective programs, and had to descope them.

In the end, the cooperative effort failed because the polar platform program was not objective driven and because the larger Space Station program from which it had emerged attempted to impose rules on Earth observations that had nothing to do with the International Space Station. Moreover, the original cooperative plan, which was to include not only the Earth science communities with NASA and ESA but also the operational segment with NOAA and EUMETSAT, may have been too ambitious for a first-time NASA-ESA Earth-observing activity. The final failure was the result of a small step (the exchange of two instruments), but the initial step taken was far too grand; there was never a clear agreement about objectives and approach.

Lessons Learned

Although there is only a limited range of truly international scientific missions in Earth observation, those that have been developed have been quite successful. For instance, UARS and TOPEX-POSEIDON returned data and information beyond all expectations of the original team of mission planners and designers. The satellites were launched successfully, operated as expected, and provided highly reliable data and new insights into atmospheric processes and ocean dynamics. These achievements came at a significantly reduced cost to each participating country.

For these Earth science missions, data have been successfully distributed to a large number of users and investigators in many countries and across various disciplines. For instance, TOPEX-POSEIDON data have been

[79] Memorandum of Understanding Between the United States National Aeronautics and Space Administration and the European Space Agency Concerning the Acquisition of ERS-1 SAR Data at Fairbanks, January 14, 1986.

used by several international oceanographic and meteorological programs (e.g., WOCE and TOGA) to obtain significant new insight into ocean dynamics and climatic effects. UARS employed a Central Data Facility where data in all forms (from raw down-link to sophisticated mapped products, plus information to facilitate its use) were available on-line to investigators around the world, following the 1-year proprietary period.

Even though these bilateral and trilateral missions have been largely successful, there has been no formal cooperation between NASA and ESA on an Earth observation mission. The only cooperative activities are between NASA and one nation (e.g., France for TOPEX-POSEIDON) or several (e.g., the United Kingdom and France for UARS). Furthermore, within the Earth sciences, there has not been a cooperative land science mission between either NASA and ESA or NASA and a European country.[80] The only cooperation in this domain has been restricted to data exchange, calibration and validation, sharing of receiving stations, or the opportunity to place European instruments on board the Space Shuttle.

Clearly Defined Mission, Significant Responsibilities on Both Sides, Clean Interfaces

The scientific value of missions has been significantly enhanced when scientists from several countries pooled their knowledge and shared their techniques. This applies equally to engineering know-how and to equipment. For instance, in TOPEX-POSEIDON, U.S. and French scientists and engineers shared significant contributions in oceanography, geodesy, altimetry, orbit calculation, and spacecraft engineering. What made this possible in practice and not just in theory was that there were relatively clean boundaries and interfaces in mission design and engineering, and each side made a significant contribution: They needed each other.

On UARS, Europe contributed instruments using techniques not readily available in the United States (e.g., pressure modulation, radiometry for composition measurements, solid-state interferometers for wind sensing); therefore, even though the contribution was not large, it was important, and the interface was clean.

Joint and Early Mission Planning

If an international mission is designed at the outset with the participation of scientists from cooperating countries, the mission has a stronger raison d'être. Experimenters from participating countries competitively bring their own know-how to the program; therefore, the mission is richer in concept than it would be without them. Also, if the experiments chosen complement each other in their quest to achieve the same objectives, the mission is more robust than it would be otherwise. In other words, a cooperative mission in which there is consensus on scientific objectives among partners and experiments that complement these objectives has a better chance of withstanding potential pitfalls than it would otherwise.

Scientists from both sides of the Atlantic must be involved in defining the concept of the mission from the beginning; mission design clearly benefits from these combined talents, but more importantly, a collective buy-in occurs. This happened in the case of UARS, whose design proved optimum to address questions and opposing hypotheses about the stratospheric sciences that were hotly debated at the time.

In TOPEX-POSEIDON there was a lengthy planning process and MOU development. This established a firm foundation for cooperation. In addition, TOPEX-POSEIDON scientists helped their counterparts on the other side of the Atlantic keep the mission planning and implementation process moving forward, even when the political or funding situation deteriorated. Without cooperation between French and U.S. scientists, the TOPEX-POSEIDON mission would never have been approved by NASA or CNES. The support of French scientists was needed for NASA acceptance, and it appears that the scientific pressure applied by U.S. scientists helped persuade CNES to

[80] However, under the new NASA Earth System Science Pathfinder Program, which requires launch within 4 years of project initiation, one of the first two selections may involve U.S.-European cooperation between NASA and DARA on the Gravity Recovery and Climate Experiment (GRACE). Final discussions are under way between the United States and Germany and could involve the purchase of a launch vehicle by Germany.

support the mission. This was not the case in the polar platform venture, which resulted in failure of the cooperation when less funding became available.

Cost Reduction

Cost sharing helped reduce the mission cost to each individual country, as noted in the TOPEX-POSEIDON example. The international cost contribution to UARS was smaller, consisting of payload instruments worth perhaps $50 million; but the technology contribution, as mentioned, reflected an importance beyond its total monetary value.

On the negative side, specific problems have been associated with mission financial support despite the overall success of missions. Because UARS was the first international Earth science mission, it was also a major learning exercise for the project teams and agencies. One of the difficulties arose when a French principal investigator, whose instrument was accepted for the UARS mission, could not get support to develop and construct the instrument in France. It was finally built by Canada with a Canadian PI. There were also said to have been difficulties for a British PI on UARS in delivering his instrument and obtaining travel support to attend science steering group meetings in the United States. Despite these problems, the UARS mission is a major success story in internationalizing Earth science missions from space.

Involvement in a Broader International Agenda

Earth observation missions provide data to more than one discipline or research project. Unlike UARS, where data were restricted to principal investigators for 1 year, TOPEX-POSEIDON data were limited only to a 6-month validation period. Moreover, data sharing for the TOPEX-POSEIDON mission was ensured not only by the MOU and other agreements, but also by the fact that it had become a vital part of an international research effort to explore ocean circulation and its interaction with the atmosphere. The mission was timed to coincide with and complement a number of international oceanographic and meteorological programs, including WOCE and TOGA, both of which are sponsored by the World Climate Research Programme (WCRP). TOPEX-POSEIDON was more than a contribution to WOCE, because WOCE was designed by taking TOPEX-POSEIDON into account. The relationship of TOPEX-POSEIDON to international research programs was, therefore, conceived beforehand.

For UARS, the relationship to international research programs was based on actual observation. UARS had been designed earlier, before *Challenger* and before the discovery of the hole in the ozone layer in 1985. However, UARS contributed directly to international concerns that were addressing changes in the chemistry of the atmosphere, including ozone depletion due to NO_x and CFCs. For example, the Montreal Protocol of 1987 called for international ozone assessments to be done on a periodic basis under the World Meteorological Organization and the United Nations Environmental Program. UARS was critical in verifying the chemistry and dynamics of stratospheric ozone reduction by actually measuring molecules such as ClO. In addition, UARS played a vital role in the development of an international project, Stratospheric Processes and Their Role in Climate, which is now a component of the WCRP.

Data Sharing

The concept of creating a central data handling facility for a given scientific mission so that the data from *all* instruments are available to *all* investigators on the mission provides an added benefit of making correlative data sets available to individual investigators. In the case of UARS, this pioneering concept in an Earth science mission helped investigators to compare their measurements with other related parameters in the stratosphere measured by other instruments on UARS and thereby provided excellent diagnostic capability to each of the investigators. In addition, when a central data handling facility is set up from which each participating scientist, regardless of nationality, can reach into and acquire the data of everyone else, common trust is built up faster and the scientific results are likely to be of higher quality. Although a central data facility was one way to collect and distribute mission data in the pre-workstation era, advances in computer technology and networks have made it easier for multiple, decentralized centers to link disparate data sets in a seamless fashion.

In fact, TOPEX-POSEIDON, which ensured data sharing in the original MOU and other agreements, took advantage of this advanced technology. TOPEX-POSEIDON data are processed, distributed, and archived by JPL's Physical Oceanography Distributed Active Archive Center (PODAAC) and by the French Space Agency (CNES) Archiving, Validation and Interpretation of Satellite Oceanographic (AVISO) Data Center in Toulouse, France. At both centers, data are readily requested via the Internet and electronic mail. Data are provided to users primarily in CD-ROM format or by electronic file transfer. Moreover, JPL, which manages the TOPEX-POSEIDON project and operates the satellite, hosts World Wide Web pages with browse files of data and images, access to near-real-time data, and other resources such as tutorials, descriptions of images, examples of oceanographic applications, and a list of investigators. The existence of two processing centers—one in France and one in the United States—with shared responsibilities, stimulated cross-fertilization and was of benefit to the scientific community. The principal investigators for TOPEX-POSEIDON also decided to give up any "proprietary access period" to the data, on the grounds that they had already a significant advantage over general users because of their depth of knowledge of the system and because they calibrated and validated the data without imposing a period of restricted access.

It is relatively easy to implement data exchange agreements for fully dedicated scientific missions with a relatively sharp focus, where the data are used primarily by the scientific community. On the other hand, multiuser, multipurpose missions that have different communities of users with different goals, from science to commercial applications, raise almost insurmountable barriers to developing data exchange agreements and policies. Therefore, it is important that agreement on the purpose of the mission and data policy be achieved very early in the process of cooperation.

To induce scientists or engineers to share their data and technology with other countries, there must be a two-way flow with a clear advantage to all sides. In the case of TOPEX-POSEIDON, each side benefited from the knowledge of altimetry, geology, oceanography, and space technology that the other side provided. However, the original agreements (or MOUs) must clearly spell out how mission data are to be shared and specifically what calibration information is to be provided.

The distribution and cost of data to participants and other users must be agreed on at initiation of the project. For most missions, agreements specify how long PIs have preferential access before the data are released to the public. Financial implications may arise if the data must be obtained through commercial channels. When scientific research has potential applications with commercial and/or industrial interests or when national interests are the driving forces, cooperation may turn into competition. These issues should be clearly addressed during the preparation phase of the mission to avoid "poisoning" the scientific cooperation. It is essential that the role and responsibilities of each partner be clearly identified as early as possible.

International cooperation in analyzing data or organizing field experiments (ground segment) has been much better than the cooperation in defining, designing, and sharing responsibilities for a space mission (space segment). International programs for analyzing the data (e.g., International Geosphere-Biosphere Program [IGBP] and the WCRP) and for organizing field experiments (e.g., WOCE, Hydrological and Atmospheric Pilot Experiment in the Sahel [HAPEX], Boreal Ecosystem-Atmosphere Study [BOREAS]) exist and have proven highly efficient.

Technology Sharing

There were problems with using each other's data due to lack of calibration information from the other side, particularly for altimeter calibration data on TOPEX-POSEIDON. Whether intentional or accidental, this deficiency might not have occurred if the original agreements had more clearly spelled out how data were to be shared, and specifically what calibration information was to be provided. Again on TOPEX-POSEIDON, there was considerable reluctance among decision-making NASA officials to share altimeter-related technology for both competitive and security reasons, and similar reluctance on the part of the French to explain details of the French system. There were no corresponding problems on UARS where an excellent spirit of cooperation was achieved throughout.

Lack of Historical Foundation

Finally, there is an implicit lesson in what is missing from our base of international experience; namely, there have been no Earth science missions jointly between ESA and NASA and no joint land missions between NASA and a European country. This area is marked by unsuccessful attempts at cooperation. Most recently, NASA was to provide an Earth radiation budget instrument to ESA's ENVISAT mission, and ESA was to provide a passive microwave instrument for flight on NASA's EOS-PM1 spacecraft. Each canceled its contribution; in both cases, cancellation proved troublesome for the other side and was done with little or no consultation or warning. This last act ended the planned cooperation between ESA and NASA in Earth science.

The reasons for the lack of success appear to be that cooperation in Earth science (as opposed to Earth observation) between NASA and ESA is relatively recent, and the undercurrent of competitive forces still influences Earth observation programs at these agencies. The lack of adequate data exchange agreements between NASA and ESA for their major Earth science missions (e.g., EOS, ENVISAT) reflect this continuing tension. It should be noted, however, that scientific cooperation between the United States and Europe in Earth sciences has increased significantly in the past 15 years, thanks to the IGBP and WCRP and other similar programs.

MICROGRAVITY RESEARCH AND LIFE SCIENCES

For microgravity research and life sciences, the future of experimentation in space for the next 20 years depends largely on the International Space Station as the laboratory in space. As is well known, Space Station is a cooperative effort among Canada, Japan, the western European community, Russia, and the United States. Hence, to a great extent, the efficacy of scientific investigations on Space Station depends on the efficacy of international cooperation. One branch of this international cooperation is, of course, efforts between the western European community and the United States.

Within this context, from the various types of missions flown thus far, the International Microgravity Laboratory (IML) missions IML-1 and IML-2 were chosen to represent the nature of international cooperation in microgravity research and life sciences. These missions exhibited characteristics of cooperative endeavors between NASA and the European agencies on Space Station and can be thought of as precursor missions for the International Space Station. IML-1 and IML-2 were particularly distinctive with respect to the variety and intensity of cooperation between Europe and the United States. The nature of the cooperation included sharing of experimental facilities as well as sharing of scientific knowledge. Also, even though a majority of the experimental facilities were provided by Canada, Japan, and western Europe, both experimental facility management and mission management were provided by the United States. Because of the particular characteristics of IML-1 and IML-2, an analysis of the experience and outcome associated with them should provide guidance for the conduct of international cooperation of the space laboratory of the future, the International Space Station.

International Microgravity Laboratory

IML-1 and IML-2 were missions in which foreign partners contributed facilities for use in life sciences or microgravity research experiments in exchange for an opportunity to place the facility aboard the Shuttle to carry out experiments in space.[81] The missions involved the CNES, the 14-nation ESA, the Canadian Space Agency (CSA), DARA, the National Space Development Agency of Japan (NASDA), and NASA.

The manifest for IML-1 was composed of 14 experimental facilities equally divided between life sciences and microgravity research. There was an additional facility for measurement of acceleration levels. The latter facility and six of the experimental facilities were provided by NASA. ESA, DARA, and NASDA each provided two experimental facilities; CNES and CSA each provided one facility. The manifest structure and diversity in

[81] Microgravity and life sciences research conducted in the space environment makes use of large facilities, such as glove boxes and furnaces, which investigators share to conduct experiments.

nationality of facilities for IML-2 was similar to IML-1: There were eight experimental facilities in life sciences and seven in microgravity research; however, most of the actual experimental facilities for IML-2 were new.

Historical Background

The initial planning meeting for IML-1 was held in July 1983. This was followed by the formation of a science working group in October 1983. The payload complement was finalized in December 1984. In 1986 *Challenger* caused a prolonged delay, within which the launch date was rescheduled nine times. The investigator working group began meeting in January 1987 and met frequently thereafter. IML-1 was ultimately launched on an 8-day mission on January 22, 1992.

Like IML-1, IML-2 had its inception in 1983 when NASA began planning the IML Spacelab missions. The preliminary payload for IML-2 was sketched out in January 1989. The payload configuration was established in October 1989. This was followed by the first meeting of the investigator working group in May 1990. Except for personnel changes, the IML-2 mission management organization was similar to IML-1. IML-2 was launched on July 8, 1994, and landed on July 23, 1994.

Cooperation

The selection of facilities to be included in IML-1 was made by NASA. Each facility was developed and provided, flight-ready, by the space agency that proposed and sponsored it. On the other hand, each space agency was individually responsible for the selection of experiments for a given facility. The responsible space agency covered the costs of the experiments it selected, regardless of the origin of the facility involved. Each major facility had its own project manager who helped coordinate the activities of individual experimenters. NASA provided overall coordination of the mission with a program scientist and program manager at its headquarters, as well as a mission manager and mission scientist at the Marshall Space Flight Center.

The life sciences facilities involved 29 separate experiments. Investigations were conducted in human physiology, space biology, radiation biology, bioprocessing, plant physiology, and human adaptation to low gravity. Three of the facilities were provided by NASA and had only U.S. principal investigators. Facilities provided by DARA and NASDA each had single experiments, with PIs from the country of origin. The facility provided by CSA was used for six experiments, all with Canadian PIs. Only one life sciences facility, the Biorack provided by ESA, was international in scope. PIs from eight separate European countries and the United States conducted 17 experiments.

Thirteen separate experiments were performed in the microgravity research facilities. The areas targeted were casting and solidification technology, solution crystal growth, vapor crystal growth, protein crystal growth, organic crystal growth, and critical point phenomena. The three facilities provided by NASA were used solely by U.S. PIs. The facilities provided by CNES and NASDA were used for single experiments with PIs from the country of origin. Two facilities, the Cryostat provided by DARA and the Critical Point Facility provided by ESA, had an international flavor. In Cryostat, two PIs were from Germany and one was from the United States; the Critical Point Facility included two PIs from France, one from the Netherlands, and one from the United States.

For specific experiments in both the life sciences and microgravity research, additional international cooperation occurred in several instances. In these cases, the nationality of the coinvestigator(s) differed from the nationality of the PI, and the data collected were shared by members of the investigative team. Altogether there were 40 PIs from 11 countries. If coinvestigators are taken into account, 220 scientists from 12 countries participated in IML-1. The countries represented were Switzerland, the United States, the Netherlands, Spain, Germany, Italy, France, the United Kingdom, Denmark, Japan, Canada, and Australia.

IML-2 continued the concept of the contribution of facilities by foreign partners for a NASA-managed Spacelab mission in exchange for the opportunity to carry out experiments in low Earth orbit. The participating agencies were identical to those that took part in IML-1. Payload selection was done by NASA, as earlier. Participating agencies were again responsible for the costs of a flight-ready facility. They were also responsible for the selection of their national experiments and the costs of supporting the experiments selected. However, the lineup of facilities was considerably different from that of IML-1. Only three experimental facilities from IML-1 were reflown on IML-2: the Biorack and Critical Point Facility provided by ESA, and the Biostack provided by DARA. The acceleration measurement facility provided by NASA on IML-1 was also reflown.

Including Biorack and Biostack, a total of eight life sciences facilities were selected for IML-2. Thirty-five separate experiments were conducted in the general areas of space biology, human physiology, and radiation biology. NASDA provided three facilities and DARA provided two, including Biostack. ESA, CSA, and NASA each provided one facility. In the latter two cases, PIs were of the same national origin as the facility itself. This was also true for one of the facilities provided by NASDA and one provided by DARA. In somewhat similar fashion, the ESA-provided Biorack had PIs only from ESA member nations; in this case, PIs from six European countries conducted experiments. Hence, PIs whose origin was different from that of the facility were present on only three of these facilities. One U.S. PI and one Swiss PI utilized the DARA-provided Slow Rotating Centrifuge Microscope along with six German PIs. One U.S. PI cooperated with three Japanese PIs to conduct experiments with the Aquatic Animal Experiment Unit provided by Japan. The second NASDA-provided facility, the Thermoelectric Incubator, had a roster of one U.S. PI and two PIs from Japan.

For carrying out experiments in microgravity research, seven facilities were selected for IML-2. Thirty-eight experiments in the general areas of materials science, fluid sciences, and biotechnology were carried out. ESA provided three facilities, including the Critical Point Facility mentioned previously. NASDA provided two facilities; CNES and DARA each provided one. NASA did not provide any of the microgravity research facilities, but at least one U.S. PI was included in every facility. In the Electromagnetic Containerless Processing Facility provided by DARA, the experimental team consisted of four U.S. PIs and four German PIs. The Bubble, Drop and Particle Unit provided by ESA involved two U.S. PIs along with four European PIs from three ESA member countries. A second ESA-provided facility, the Advanced Protein Crystallization Unit, involved a U.S. PI cooperating with 10 European PIs from five ESA-member countries. ESA's Critical Point Facility included one U.S. PI with three European PIs from three ESA member countries. One French PI and one U.S. PI participated in using the French-provided facility, Applied Research on Separation Methods Using Electrophoresis. Each of the NASDA-provided facilities, the Free-Flow Electrophoresis Unit and the Large Isothermal Furnace, accommodated one U.S. PI along with two PIs from Japan.

Three additional facilities flown on IML-2 were dedicated to experiments and measurements for characterization of the microgravity environment and countermeasures. One facility, which had previously flown on IML-1, was provided by NASA. The other two were provided by DARA and NASDA. Four experiments were done. The PIs in each case represented the nationality of the facility-providing agency.

Because of multiple experiments by three PIs, 73 individuals carried out a total of 77 experiments on IML-2. As was true for IML-1, coinvestigators were associated with most of the PIs. Also, like IML-1, in several instances the nationality of the coinvestigators differed from that of the PI. Including coinvestigators, 198 scientists from 13 countries were involved in conducting experiments on IML-2. The countries represented were Switzerland, the United States, the Netherlands, Spain, Germany, Italy, France, the United Kingdom, Japan, Canada, Norway, Belgium, and Sweden.

Summary

For both IML-1 and IML-2, a range of experimental and programmatic success was experienced. Some PIs reported complete success, many reported significant success, and others reported relatively minor success or none. The reasons were similar to other areas of successful cooperation in space: clean interfaces, good communication between all parties, favorable cost-benefit ratios, and synergistic effects. Instances of less-than-complete success were often accompanied by situations in which the interfaces and communications were faulty and the scientists were not "in charge."

There are, also, some insights unique to IML, such as the amplification of cooperation through the development of "generic" equipment that different partners must use, although this amplification was not always free of problems. However, it is important to note that many of the same problems that existed, and still continue, on international missions in the life and microgravity sciences also occur on national missions. These problems tend to be magnified in any international undertaking, making them somewhat more complicated to resolve.

Lessons Learned

Benefits Should Clearly Outweigh Costs

One primary benefit was the distribution of costs for performing experiments in low Earth orbit. Both NASA and the European partners provided equipment and selected experiments for the IML missions, whereas NASA provided mission management and launches. Cooperation spread the cost of hardware over a wider base. Neither NASA nor the foreign partners could have provided such a wide spectrum of equipment from their own resources. For U.S. investigators this arrangement provided an opportunity to make use of equipment that would otherwise have not been available to them.

The international missions were an economic advantage to both the United States and the foreign partners. Each country was able to mount important experiments with less total cost to itself. European scientists were able to put experiments into space at a reduced cost, compared with development of their own launch vehicle. For the United States, the availability of "free" hardware in exchange for flight possibilities was an important economic consequence. For example, without this, the IML-2 mission would never have flown, since NASA was unable to provide the budget needed for any hardware development. Another economic benefit is that this collaborative approach to developing hardware has resulted in a larger stock of apparatus available for experiments on subsequent flights. Some of the pieces of hardware have already been used on other flights.

Synergism

An important benefit of international cooperations is the synergism that develops between and among scientists, scientists and engineers, scientists and managers, and engineers and managers from different countries. A wider range of expertise was available for the generation of equipment concept, development, and implementation, as well as for improving the concept of experiments and experimental protocols. In many cases, the resulting experiments were better than they would have been if participants had been from only a single country. Furthermore, the missions promoted cooperation among scientists from different countries that have resulted in long-lasting scientific collaborations.

The international cooperation in these missions had a major synergistic effect on the science that could be performed. Neither U.S. nor European scientists could have accomplished nearly as many spaceflight experiments without this cooperation. The United States had the only vehicle capable of carrying these experiments into space but relatively limited amounts of equipment or budget to produce such equipment. The Europeans, on the other hand, had no access to space on their own because they had no launch vehicle, but they had both the funding and the interest to provide equipment suitable for these experiments in microgravity research and life sciences. Thus, by combining their efforts, a maximum amount of science was achieved. This lesson has clearly already been learned with regard to the Space Station.

Development of Generic Equipment

It was perceived that the development of multiuser (generic) hardware by a specific national entity would always be valuable to scientists from other nations, who might then be able to use the equipment for their own experiments. To a certain extent this has been true, and equipment proved to be truly generic. However, two problems have occurred. Generic hardware often imperfectly accommodated given experiments within the set of equipment for which the hardware was said to be designed. In addition, some scientists found that generic hardware was insufficient for their needs. In some cases, facilities were not generic in that the hardware was developed for a defined set of experiments. By the time additional international PIs were added, it was usually too late to effect any meaningful changes to the apparatus so as to accommodate other, diverse experiments.

Given such experiences on the IML missions, PIs should be more closely involved in the definition of facilities and equipment. At present, facilities tend to be designed by committees that try to make the apparatus as multiuser as possible. Although this is a desirable goal, some of the equipment problems might be alleviated if PIs were involved earlier.

Hardware Failings and Communication

The two IML missions conducted 119 experiments. More than 400 scientists participated, including both principal investigators and coinvestigators from 15 countries. There were failures and mixtures of degrees of success, as well as major difficulties encountered by some PIs. In some cases the hardware failed to live up to expectations. Severe difficulties with some of the hardware was brought on in part by insufficient communication between the hardware development engineers and the PIs who were going to use the equipment. Often, hardware development had proceeded too far before international PIs came on board. In addition, there were cases in which communication difficulties between various players were exacerbated by the diversity of nationalities, different agendas of the international entities, and geographic separation of participants. Improvements in communication among engineers and scientists will be important for the Space Station. There is no excuse for flight equipment to be flown that has not been ground tested or does not work properly.

Resource Allocation

PIs also faced the difficulty of resource allocation, which is particularly important on relatively short Shuttle-based mission. It is even more demanding on international missions that may have conflicting agendas.

Because of the wide range of nations involved and an accompanying diversity in scientific priorities, there were myriad experiments on IML-1 and IML-2. In the planning of missions there was no great concern about the overbooking of resources, even though a large number of experiments were to take place. Many believed that the diversity would, in fact, lend itself to compatibility with resources. In particular, the inclusion of both microgravity research and life sciences experiments was thought to be a benefit; the life sciences experiments were expected to be crew intensive, whereas the microgravity research experiments were expected to be power intensive. This outlook proved to be too simplistic. The missions showed that an analysis of mission experiments and resource availability must be conducted down to the subdiscipline level.

The unavoidable conclusion is that on IML-1 and IML-2, the resources were seriously overbooked. This includes data downlinks, direct TV coverage of experiments, and crew time. Crew time was so heavily booked that when some of the crew were unable to perform for periods of time, there was not enough slack in the system to compensate. This problem was exacerbated by the interruptions of crew time for public relations or outreach teaching performances. As a result, in some investigations, critical data points were simply not collected, and the experiments were seriously compromised. The success of scientific experiments should not be jeopardized by the unexpected insertion of public affairs into the time line. Proper planning with the public affairs office will alleviate this issue.

Experience has shown that at times the crew's efficiency in space is lower than when they are on the ground, so it is better to fly fewer experiments and have them all succeed rather than fly too many that end up being incomplete.

Archiving and Accessing Data[82]

The IML missions contained a wide range of science, experiments, and experimenters from all over the world. Hence, results obtained are published in a variety of journals and conference proceedings. For IML-1 and IML-2, there is no single source summary of scientific results. One has to comb through a considerable number of sources

[82] For more information about archiving, see Committee on Microgravity Research, Space Studies Board, NRC, *Archiving Microgravity Flight Data and Samples,* National Academy Press, Washington, D.C., 1996.

to learn the efficacy of the missions. Then too, many of the experiments may never be published, especially if they were not considered a scientific success by the PI. There is therefore a need for proceedings of international cooperation in microgravity research and life sciences. Moreover, in formulating international missions in microgravity research and life sciences, partners should reach agreements that articulate how the results are going to be disseminated and identify the obligations of all PIs to contribute to a single book on mission results. However, the format of such a publication should be such that the material would not preclude parallel publication in refereed journals.[83] An example to be followed is that of the D-2 mission, which published a single volume containing information and basic findings from every experiment on the mission.[84]

Communication

Considering the potential for difficulties in managing these complex international missions, the management succeeded better than anyone could have expected. Some problems arose, and there were too many levels of management between the PI and the mission, but few concrete suggestions were made about ways to improve mission management. There were suggestions, however, about the need for better communication between the agencies. European scientists need to be better informed about NASA's requirements, rules, and procedures. Similarly, U.S. scientists need to understand that the administrative structure for spaceflight experiments is somewhat different in Europe. Improving these types of communication might make it easier for European scientists to adjust to some of NASA's requirements.

[83] IML-1 "Quick Look," documentation dated April 6, 1992; IML-1 Brochure IML-1 payload confirmation documentation; correspondence from Dr. Robert Snyder, mission scientist for IML-1 and IML-2, dated May 13, 1996; IML-2 payload confirmation documentation, dated January 12, 1993.

[84] Sahm, P.R., Keller, M.H., and Schiewe, B., eds., *Proceedings of the Norderney Symposium on Scientific Results of the German Spacelab Mission D-2, March 14-16, 1994, Norderney, Germany,* Wissenschaftliche Projektfuhrung D-2 Mission, Cologne, Germany, 1995.

4

Findings and Recommendations

Scientific cooperation between the United States and Europe in space science, Earth sciences, and microgravity research and life sciences (MRLS) has proven very important. In the most successful examples, cooperation has produced significant scientific results, cost savings for each partner, effective synergism among technologies, and improved access to U.S. and European data. Many missions benefited from one or more of these advantages, but some encountered pitfalls.

The joint committee, having surveyed and analyzed the 13 U.S.-European cases discussed in Chapter 3, identified several conditions that either facilitated or hampered bilateral or multilateral cooperation in space science. Some of these lessons are unique to their scientific disciplines and their "cultures," whereas others are cross-cutting and apply overall, to the cooperative experience between the United States and Europe, as analyzed in chapters 2 and 3. The joint committee determined that these overarching findings can be organized according to the various phases of a cooperative program, namely, (1) goals and rationale for international cooperation, (2) planning and identification of cooperative opportunities, (3) management and implementation, (4) personnel, and (5) guidelines and procedures. The findings lead to five sets of recommendations.

The findings emphasize the respective roles of people and communication issues on one hand and of planning and management issues on the other. Both are essential, but their relative weight may depend on mission type as well as on the balance and sharing of responsibilities among partners. Depending on the issue that is considered pivotal (either the personnel perspective or the planning and management one), the findings of this committee and the corresponding recommendations could have been grouped in different ways.[1]

The joint committee's findings, derived from past experience, apply as well to future cooperation. As the political context for both Europe and the United States evolves in the post-Cold War era, the number of potential space partners, such as newly democratic Eastern European countries, increases, and new institutions and commercial entities enter the scene. In the United States, for example, start-up companies seek to profit from high-resolution Earth observation imagery, whereas across the Atlantic, the European Union has taken on a broader role in space policy. The circumstances and particulars of the environment are changing and producing countervailing

[1] To emphasize the importance of people and their role in planning, management, and implementation of the programs, the order of the sections on planning, management and implementation, and personnel could have been interchanged, placing the recommendations concerning personnel at the beginning, after the description of the goals and rationale for international cooperation. Clearly good people are important to mission success; similarly, poor management practices can significantly hamper the most highly motivated team.

forces for cooperation. Constrained budgets at the national level have made cooperation more appealing, but these same forces have also led to management and structural reorganizations within national and multinational space agencies that may be an unintended obstacle for international cooperation. At the National Aeronautics and Space Administration (NASA), for instance, the agency's shift to a "smaller, faster, cheaper" policy and an emphasis on small satellites has left questions as to how international cooperation fits in. Such organizational changes within NASA and the European Space Agency (ESA) introduce new challenges as well as improvements for cooperation, and these changes shift the context of the recommendations and findings. The joint committee has tried to be sensitive to these shifts in extracting lessons from the past, but it has not tried to forecast the future.

GOALS AND RATIONALE FOR INTERNATIONAL COOPERATION

The joint committee's examination of U.S.-European missions over more than 30 years shows, in retrospect, that international cooperation has at times been used to justify a scientific mission that may have lacked support from the scientific community at large or other factors important for successful cooperation. (This was particularly true for the International Gamma-Ray Astrophysics Laboratory [INTEGRAL] mission, which lacked broad support within the U.S. astronomical community.)

1. *Scientific support.* The international character of a mission is not a guarantee of its realization. The best and most accepted method to establish compelling scientific justification of a mission and its components is peer review by international experts. Expert reviewers can verify that the science is of excellent quality and meets high international standards, the methods proposed are appropriate and cost effective, the results meet a clear scientific need, there are clear beneficiaries in partners' countries, and the international program has clear requirements.

The difficulties faced with INTEGRAL on the U.S. side are partly a case in point. From a budgetary and political point of view, the mission must have strong support from the scientific community in a timely manner to overcome budget restrictions (and political hurdles), as proven positively by the Ocean Topography Experiment (TOPEX-POSEIDON) and negatively by the International Solar Polar Mission (ISPM, later renamed Ulysses). All partners and funding agencies need to recognize that international cooperative efforts should not be entered into solely because they are international in scope.

2. *Historical foundation.* The success of any international cooperative endeavor is more likely if the partners have a common scientific heritage—that is, a history and basis of cooperation and a context within which a scientific mission fits. This context encompasses a common understanding of the science that can lead to the establishment of common goals. A common heritage also allows the scientific rationale to be tested against other priorities. There is an obvious shared heritage simply among scientists, but more is implied here. The originally proposed cooperation between ESA and NASA on the polar platforms involved too large a step based on too little shared experience. The failure of this effort should not have been surprising.

3. *Shared objectives.* Shared goals and objectives for international cooperation must go beyond scientists to include the engineers and others involved in a joint mission. One of the most important lessons learned from the years of space research is that "intellectual distance" between the engineering and scientific communities and the accompanying lack of common goals and objectives can have a detrimental effect on missions. The penalty is that the mission project is, at best, only partially successful and, at worst, a total failure. Close interaction is particularly important at the design phase—for example, the participation of scientists in monthly engineering meetings can help to support optimal planning when compromises are needed between scientific goals and technical feasibility.

4. *Clearly defined responsibilities.* Cooperative programs must involve a clear understanding of how the responsibilities of the mission are to be shared among the partners, a clear management scheme with a well-defined interface between the parties, and efficient communication. In successful missions, each partner has a clearly defined role and a real stake in the success of the mission. AMPTE and TOPEX-POSEIDON are particularly good examples of the importance of effective communication and balanced, shared responsibilities.

5. *Sound plan for data access and distribution.* Cooperative ventures should have a well-organized and agreed-upon process for data calibration, validation, access, and distribution.

6. *Sense of partnership.* The success of an international space scientific mission requires that cooperative

efforts—whether they involve national or multinational leadership—reinforce and foster mutual respect, confidence, and a sense of partnership among participants. Each partner's contributions must be acknowledged in the media and in publications resulting from joint missions.

7. *Beneficial characteristics.* Shared benefits such as exchanges of scientific and technical know-how and access to training are not usually sufficient justification to sustain an international mission. Successful missions have at least one (but usually more) of the following characteristics:

- Unique and complementary capabilities offered by each international partner, such as expertise in specific technologies or instruments or in particular analytic methods;
- Contributions made by each partner that are considered vital for the mission, such as providing unique facilities (launchers, space observatories, or laboratories), instruments, spacecraft subsystems, or ground receiving stations;
- Significant net cost reductions for each partner, which can be documented rigorously, leading to favorable cost-benefit ratios;
- International scientific and political context and impetus; and
- Synergistic effects and cross-fertilization or benefit.

8. *Importance of reviews.* Periodic monitoring of science goals, mission execution, and the results of data analysis ensure that international missions are both timely and efficient. This is particularly important if unforeseen problems in mission development or funding result in significant delays in the mission launch or if scientific imperatives for the mission have evolved since the original mission conception or development. A protocol for reviewing ongoing cooperation activities may avert the potential for failed cooperation and focus efforts only on those joint missions that continue to meet a high priority for their scientific results.

In the case studies considered, there may have been increased costs associated with international cooperation, but these costs were offset by the benefits. None of the case studies analyzed revealed any net cost increase resulting from international cooperation. However, it is worth noting that when international cooperation fails or breaks down, there are costs incurred that might otherwise have been avoided.

Recommendation 1

The joint committee recommends that eight key elements be used to test whether an international mission is likely to be successful. This test is particularly important in the area of anticipated and upcoming large missions. Specifically, the joint committee recommends that international cooperative missions involve the following:

- ***Scientific support through peer review that affirms the scientific integrity, value, requirements, and benefits of a cooperative mission;***
- ***An historical foundation built on an existing international community, partnership, and shared scientific experiences;***
- ***Shared objectives that incorporate the interests of scientists, engineers, and managers in common and communicated goals;***
- ***Clearly defined responsibilities and roles for cooperative partners, including scientists, engineers, and mission managers;***
- ***An agreed-upon process for data calibration, validation, access, and distribution;***
- ***A sense of partnership recognizing the shared contributions of each participant;***
- ***Beneficial characteristics of cooperation; and***
- ***Recognition of the importance of reviews for cooperative activities in the conceptual, developmental, active, or extended mission phases—particularly for foreseen and upcoming large missions.***

NASA and the international partners should reflect on the nature of the existing International Space Station (ISS) program compared with past programs that resulted in successful international cooperative efforts. Failure to ensure the elements characteristic of successful cooperation could well spell failure for the ISS and the Space

Station Utilization Programs. This is crucial, particularly for MRLS, because the Space Station is expected to be the overwhelmingly dominant platform for carrying out international cooperative research in low Earth orbit.

In its review, NASA and its partners should unequivocally define the purpose, goals, and objectives of the Space Station and the corresponding utilization programs. The Space Station's role may be abundantly clear within the agencies but does not appear to have been agreed upon and concisely stated to the communities it is to serve. The defined goals should be stated to the scientific community, to the public, and all the governmental funding bodies involved.

PLANNING AND IDENTIFICATION OF COOPERATIVE OPPORTUNITIES

Because planning, implementing, and managing are done by people, the findings and recommendations in the next two sections overlap somewhat with those in the section on personnel. Each area is vital. Even good people find it difficult to overcome poor planning. The joint committee finds the following:

Finding: Planning for international missions has typically not been well coordinated with other national programs or activities. Missions have been developed with similar, if not redundant, capabilities.

Recommendation 2

With respect to cooperation between NASA and the European Space Agency, the joint committee recommends that coordination between the planning and priority-setting committees of these agencies be enhanced to ensure that in an era of declining resources, missions are carefully considered to ensure their unique scientific contribution and global interdependence as well as their national impact.

The currently constituted strategy and planning committees at both NASA and ESA should each have annual meetings in which several representatives of the other committee are invited to present and discuss strategic plans and missions under consideration. This information exchange may avoid development of redundant experiments or missions, which occurred in the very similar radar missions to monitor ocean waves that were launched by the United States, Europe, Japan, and Canada. Annual consultations among the standing committees and individual members will also ensure that the interests of national pride, technological readiness, and resources are not obstacles to sensible international cooperation for future missions in space.

Recommendation 3

Regarding cooperation between NASA and European countries, the joint committee recommends that scientific communities in the United States and Europe use international bodies such as the International Council of Scientific Unions (ICSU), the Committee on Space Research (COSPAR), and other international scientific unions to keep informed about planned national activities in the space sciences, to identify areas of potential program coordination, to discuss issues and problems (e.g., technology, data sharing and exchange, cultural barriers) related to international cooperation, and to share this information with national agencies.

Finding: Clear, open communications are particularly important for international missions in space science to ensure that the cooperative space effort has clearly articulated common goals and responsibilities and that mission results will be freely available. Missions with active science working teams and external user committees provide the best communications both within the project team and with the greater community.

Furthermore, it is critical to form an active sense of community with excellent communication among scientists, developers, engineers, and managers from all parties involved in carrying out the mission. Principal investigators[2] have experienced cases in which poor communication with managers and developers resulted in science

[2] For the purposes of this report, the following definitions are used:

- *Principal investigator:* a scientist who conceives of an investigation, is responsible for carrying it out, reports on the results, and is responsible for the scientific success of the investigation;
- *Program scientist*: a scientist who defines the policy and scientific direction of a program, establishes the mission science and applications objectives, and guides the science team to ensure that the scientific objectives are met;

return that was significantly below expectations. On the other hand, when scientists, developers, and managers were a true community, mission and instrument requirements were sharpened, design was improved, performance was excellent, and science return met or even exceeded expectations. Such successful cooperation usually involved a strong program scientist whose basic responsibility was to carry out the mission.

TOPEX-POSEIDON represents an example in which positive communication among various team members prevailed, whereas the case of IML-1 and IML-2 points to communication difficulties and some resulting losses in the scientific return from the mission.

Recommendation 4

Given the important role that PIs in Europe and the United States have in leading and coordinating joint PI missions, the joint committee recommends therefore that for non-PI missions (in particular, multiuser ones such as those for microgravity research and life sciences and Earth observation), two program scientists of stature, one U.S. and one European, be appointed at an early stage of joint planning to lead and coordinate the mission.

Recommendation 5

The joint committee recommends that only those international cooperative efforts be attempted in which participants consider themselves partners (even if their respective responsibilities and contributions are different) and have confidence in one another's reliability and competence as well as their dedication to the overall mission goals.

MANAGEMENT AND IMPLEMENTATION

The management and implementation of cooperative missions rely not only on clearly established goals and rationale and good planning, but also on capable personnel. Similarly, poor management practices can significantly hamper even the most highly motivated team.

The joint committee found the following:

Finding: A clear management scheme with well-defined interfaces between the parties and efficient communications is essential.

Recommendation 6

The joint committee recommends that, at the earliest stages of each international space research mission, the partners designate (1) two management points of contact, one U.S. and one European; (2) a project structure led by two designated PIs or program scientists, one U.S. and one European; and (3) an International Mission Working Group (IMWG) established with the two PIs or program scientists as co-chairs.

The IMWG provides a forum for communications between and among team members and should include key mission scientists and engineers as well as industry and agency representatives. The co-chairs ensure that science goals are paramount in planning and execution of the mission, including possible changes and descoping in response to mission contingencies. The IMWG enables communication with the respective national agencies and ensures that each partner is kept informed of any changes in mission status or support. It also provides for common interface and document control between mission partners and agencies to allow for possible differences in reporting standards and practices that may be significant for international missions. During mission operations and data analysis, the IMWG also ensures the establishment of data quality and archives, accessible databases, and data

- *Project scientist:* the scientist who leads a mission's science team and coordinates with the program/project manager to ensure that the science requirements of an investigation are met;
- *Program manager:* an individual responsible for cost, schedule, and technical performance of a multi- or single-project program and who oversees the project managers for integrated program planning and execution; and
- *Project manager:* an individual who manages the design, development, fabrication, and test of a project.

analysis tools. The IMWG should provide for the timely publication of mission results and dissemination to the public at large.

The establishment of an IMWG for each mission may take time—hence the recommendation to designate early on program management points of contact and a project structure that could be led by designated PIs or program scientists.

This is particularly urgent in the Space Station program. If NASA and its partners are committed to a scientific role for the Space Station, ISS program scientist positions should be established. Program scientists should have the responsibility for performance requirements compliance. The program scientists should also be responsible for interacting with the engineering community and the entire utilization community (national, international, and public) to coordinate how the program is defined and implemented. In addition, program scientists should be responsible for fostering relationships between the engineering community and the scientific community to build a broader integrated program community.

Likewise, program scientist positions should be continued and strengthened at the Space Station facility (instrument and experiment) level. There has been a tendency within Spacelab missions to design facilities too broad in their intent in order to accommodate a multitude of users. Also, at the facility level there have been instances where communication among scientists, developers, and managers across national and international lines was inadequate. The program scientists should be charged with ensuring the performance of facilities according to scientific objectives that do not become so generic that specific experiments are compromised. Moreover, the program scientists must build a community at the facility level.

Finding: The lessons learned show the importance of defining a protocol for reviewing the ongoing cooperative activities by independent bodies, to ensure that these endeavors are both timely and efficient and that the high-priority criterion for scientific research is still met.

Recommendation 7

The joint committee recommends that each international mission in the space-oriented sciences be assessed periodically for its scientific vitality, timeliness, and mission operations, if a significant delay in mission development or if mission descope is necessary because of funding difficulties or other factors. For each cooperative mission, the participating space agencies should appoint a separate International Mission Review Committee (IMRC) composed of distinguished peers in science and engineering to review the overall vitality and value of the mission. The IMRC should be independent from the IMWG and the mission PIs. After the prime mission phase, the extension of mission operations and funding allocations from participating agencies for mission operations and analysis phases should be assessed by the IMRC.

PERSONNEL

A prerequisite for good cooperative efforts between people is that they be recognized for their particular contributions, responsibilities, and roles (as noted also in the discussion in the section on management and implementation).

Finding: Experience shows that the roles and contributions of some partners in the success and results of a mission have not been sufficiently recognized or have even been overlooked in publications and in the media.

Recommendation 8

The joint committee recommends that the participation of each partner in an international space-related mission be clearly acknowledged in the publications, reports, and public outreach of the mission.

Finding: Those missions with the smoothest cooperative efforts had project managers on both sides of the Atlantic with mutual respect for each other. Clear scientific leadership is important for all types of missions. PI-type missions such as the Active Magnetospheric Particle Tracer Explorer (AMPTE) gained from having dedicated PIs maintain fundamental objectives and ensure data quality and distribution throughout the project.

Finding: Having assessed several cases, the joint committee found that even the best and seemingly most precise formulations of MOUs and other agreements may be subject to differences in understanding (especially in times of financial or political difficulties). This is because of cultural differences or lack of effective communication between key individuals.

Finding: Because of the observed intellectual distance among scientists, engineers, and managers, good communication among these team members is an important ingredient of successful and smooth international cooperation. These interface problems are more critical in international cooperation, because of the added barriers of culture, language, and agency procedures that can further impede effective communication.

Recommendation 9

The joint committee recommends that program and project scientists and program and project managers be selected who have (1) a strong commitment not only toward the recognized mission objectives, but also toward international cooperation, and (2) excellent interpersonal skills, since it is important that key leaders and managers seek practical means for minimizing friction in joint U.S.-European missions.

GUIDELINES AND PROCEDURES

Finding: The joint committee found that international cooperation has been hampered by nonessential administrative requirements, lack of timely information on both sides of the Atlantic, and changes in budget policies.

There are many examples in which the two partners in a transatlantic cooperation succeeded, having overcome the difficulties imposed by their different selection and funding sequences. In the SOHO case, for example, there were points in the cooperative processes where agencies on both sides responded quickly and effectively to handle hardware problems, schedule delays, launch difficulties, and other unforeseen challenges in order to bring the mission and the cooperative effort to fruition. Other cases were not successful, and the envisaged cooperation did not materialize.

Recommendation 10

The joint committee recommends that NASA, ESA, and other international partners review their own internal rules and processes (particularly those that influence international collaboration and cooperation) and seek changes that might foster and improve the opportunities for international cooperation. At a minimum, the agency partners should improve procedures so that the existing rules and processes can be more effectively explained to all participants. In particular, the necessary financial commitments should be provided on all sides, and contingencies should be agreed upon. These commitments must be made more stable, especially on the U.S. side.

Finding: International cooperation may be hampered by national interests and issues involving political, economic, and trade policies that may extend well beyond the boundaries of the individual space agencies involved:

- Export-import difficulties may affect the exchange of technology or technical information critical to a joint mission opportunity;
- Data exchange policies and commercial interests may also impede access to scientific data on cooperative missions;
- Laws governing intellectual property rights may restrict information flow or lead to difficulties in bilateral or multilateral U.S.-European space cooperation; and
- Failings within the MOU process can create delays, losses of scientific opportunities, lost economic investments, and a decline in international goodwill, all of which can weaken the foundation for future cooperative activities.

Recommendation 11

In light of the importance of international cooperative activities in space and given the changing environment for cooperation, the joint committee recommends that the national and multinational space agencies

advise science ministers and advisers on the implications that particular national trade, export-import, data, and intellectual property policies may have on important cooperative space programs. As these types of problems on a particular mission arise, the agencies should encourage these ministers or advisers to bring such issues to the agenda of the next G-8 meeting.

Finding: To better phase the development of missions, the joint committee found that establishing milestone agreements in cooperative missions would be useful. The agreement between agencies (generally the MOU) is the key formal document defining the terms and scope of the cooperation. Often, the comprehensiveness and clarity of this agreement have contributed significantly to the success of international cooperation in each discipline. Conversely, some of the difficulties encountered in several case studies can be traced in part to inadequate specificity in the agreement, or to misunderstanding or differing perceptions as to the status or interpretation of the agreement and the level of commitment implied by it. The observation that bilateral agreements between NASA and individual national space agencies appear generally less problematic than those between NASA and ESA may reflect the fact that NASA is itself a national agency, whereas ESA is a multinational organization with necessarily different perspectives. NASA-ESA cooperation refers to larger, more expensive, and more complex missions than cooperative activities between NASA and European countries.

The joint committee believes that the interests of all parties are best served when agreements have maximum clarity and specificity as to the scope, expectations, and obligations of the respective agencies and relevant scientific participants. Given the inevitable mismatch between the procedures, practices, and budget cycles of NASA and ESA, in particular, the agreements must serve as essential interface control documents. Because the expectations and the level of commitment evolve as a mission is defined and developed, the need for written agreements also changes. Establishing clear agreements would be facilitated if NASA and ESA could agree in advance on a set of generic mission milestones with clear definitions and on template agreements that certify the passage of such milestones, the anticipated progress toward the next milestone, and the expectations and time line for achieving it.

Recommendation 12

The joint committee recommends that for cooperative missions in space-based science NASA and ESA establish a clearly defined hierarchy of template agreements keyed to mutually understood mission milestones and implementation agreements.

A suggested example of a set of template agreements is given in Table 4.1, which describes a progression, with the Letter of Mutual Interest, Letter of Mutual Intent, Study MOU, and Mission MOU corresponding roughly to the usual Pre-phase A, Phase A, Phase B, and Phase C/D of space science missions. Only a fraction of missions would be expected to proceed through the full cycle, and each agreement could clearly state the likelihood of proceeding to the next stage.

Recommendation 13

In light of the continuing scarcity of future resources, the volatility of the U.S. budget process, and the importance of trustworthy international agreements supporting cooperative efforts in space, the joint committee recommends that international budget lines be added to the three science offices within NASA to support important peer-reviewed, moderate-scale international activities.[3]

Finding: The free and open exchange of data lies at the heart of international scientific cooperation.[4] When it is missing (as in the case of NASA and ESA in the area of Earth science), significant scientific international cooperation is difficult, if not almost impossible.

[3] Although multiyear appropriations for international missions might be preferred, Congress has been reluctant to authorize such multiyear commitments because of the inflexibility it creates in the appropriations process.

[4] National Research Council, *Preserving Scientific Data on Our Physical Universe: A New Strategy for Archiving the Nation's Scientific Information Resources*, National Academy Press, Washington, D.C., 1995.

TABLE 4.1 Hierarchy of Template Agreements for Cooperative Missions

Mission Phase	Agreement	Content
Pre-phase A	Letter of Mutual Interest	• Identify potential high-priority missions under consideration • Identify which bodies are studying them • Determine how many are likely to be confirmed, and when
Phase A	Letter of Mutual Intent	• Establish an early program management and project structure and an International Mission Working Group (IMWG) with two program scientists or principal investigators as co-chairs • Define objectives, scope, and expectations for Phase B • Review project management scheme
Phase B	Study Memorandum of Understanding (MOU)	• Clarify objectives and scope • Formulate anticipated implementation plan • Outline responsibilities • Select launcher • Provide a rough schedule • Determine expectations for funding
	Mission MOU	• Create full definition of objectives, scope, plan, schedule, contingencies, and data issues • Include project management plans
Phase C/D	Eventually, when necessary, appointment of an International Mission Review Committee (IMRC)	• Conduct periodic reviews of mission and effectiveness of its service to user community

Recommendation 14

The joint committee recommends the following:

- ***NASA and European space agencies should make a commitment to free and open exchange of data for scientific research as a condition for international scientific cooperation after any proprietary period established for principal investigators;***
- ***The scientific community, through their international organizations (e.g., ICSU, COSPAR), should openly and forcefully state their commitments to this concept and where there are difficulties; and***
- ***U.S. and European space agencies should ensure that programs plan and reserve adequate resources for management and distribution of data and develop and implement strategies for long-term archiving of data from all space missions.***

CONCLUSIONS

This report has highlighted the many and varied cooperations that have taken place between Europe and the United States. Many of these have been successful and have led to high-quality science and improved international understanding. However, the cooperative ventures have ranged from great success to complete failure.

Although there is no one way to carry out international missions that guarantees success, this study has identified common factors that should be used to maximize successful international cooperation.

Despite the long history of cooperation and clear lessons that can be learned from it, space agencies sometimes revert to practices that complicate international cooperation. For example, programs continue to be reviewed nationally, even on existing international cooperative endeavors, and international aspects are often underrepresented in such reviews.

The purpose of this report is to improve the strength and breadth of the foundation for international cooperation in space. Its value may be even more important in the future. Not only will resources continue to be scarce, but other, new tensions will arise as well. From the U.S. side, the declassification of Strategic Defense Initiative technologies and their use in small civilian satellites have generated a technological gap between the United States and Europe as far as miniaturization is concerned. The "smaller, faster, cheaper" policy, and the resulting shorter time for responding to Announcements of Opportunity (AOs), may render cooperation with ESA and European countries more difficult, at least in terms of small satellites. Important pathfinding missions, perhaps within an international budget line, could be particularly valuable in the future. More generally, agencies should consider the international dimension in the selection of small as well as large missions to ensure complementarity in international efforts.

From the European side, following the difficulties encountered during ISPM and the Comet Rendezvous Asteroid Flyby (CRAF) program,[5] "the scientists recommend European self-sufficiency in respect to these cornerstone missions of Horizon 2000 Plus. While being open to participation by other agencies, their execution should not depend on decisions taken elsewhere."[6] Such a recommendation may well mean that the likelihood of joint U.S.-European missions has been diminished for important cornerstone missions. Furthermore, the structure and financial time line of the mandatory program in space sciences results in a certain rigidity that makes it more difficult to match time frames on both sides of the ocean. Thus, the possibility of international cooperation between ESA and the United States on medium-size missions is reduced.

In addition, global political and economic environments are changing the face of international cooperation and will continue to do so. Among these factors are the following:

- New types of space cooperative efforts with Russia;
- Fundamental changes in the rationale for funding space research in the United States and Europe, and corresponding reductions in funding on both sides of the Atlantic;
- Establishment of new policies for space research activities in the United States and Europe;
- Increasing emphasis on the applications of space research having commercial and/or industrial returns, particularly in Earth observation;
- Increasing use of networks, such as the Internet, which imply the establishment of new data policies that take into account scientific and technical needs;
- The appearance of new European actors in the space arena, namely the European Union, the European Parliament, and the European Organisation for the Exploitation of Meteorological Satellites; and
- The establishment at the beginning of the next millennium of a new facility, the Space Station, which is likely to have an impact (either directly or indirectly) on the nature of international cooperation across the space science disciplines.

In this context, the lessons learned clearly show that there are no successful international cooperative efforts without the will for and interest in such cooperation being strongly shared among the scientific communities, programmatic entities (space agencies and/or scientific organizations), and engineering or technical bodies that design and build the missions. However, the analysis of international cooperation also shows that the will to cooperate can be hampered by excessive national pride, competition (rather than cooperation), and the need to

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[5] The failure to achieve broad U.S. participation in INTEGRAL confirmed for many Europeans the wisdom of redefining boundary conditions for cornerstone missions.

[6] European Space Agency, *Beyond This World* (ESA-BR112), Paris, France, May 1995, p. 133.

support national industries. In fact, underlying the natural desire that much of the scientific community feels toward cooperative ventures are fundamental questions:

- Why cooperate while having to defend national industrial policy?
- Is international cooperation the best way to carry out space research or develop specific space experiments?
- What is the balance among cost savings, scientific return, and benefits from the cooperative effort, compared with national priorities, freedom of programming, national independence, national pride, and preservation of employment?

Analysis of past experiences has shown that the answers to these questions have a strong impact on international cooperative activities and that the will of politicians to foster such cooperation is essential. In fact, the interest and value of cooperative endeavors should be measured in cost savings or programmatic constraints as well as in terms of the international benefit for the partners, the gain in science and engineering achievements, and the political benefits. There should be recognition at all levels and in all spheres that international cooperation (as represented by the programs agreed on) is good and necessary in its own right. These potential benefits accrue not only from a purely scientific point of view but also in independent cost savings, with each partner being stimulated and benefiting from the skill and experience of the best scientists (whatever their nationality) and obtaining the best scientific results from the funds invested.

If the interest and the will of governments is essential to the success of international cooperation, it is a necessity often missing in practice. When there are problems in other areas (resulting in cost overruns, for example) political support becomes essential if international cooperation is to succeed. When such governmental support does not exist, politicians may feel free to modify (deliberately or otherwise) the conditions under which a project operates, and international cooperation could be jeopardized.

Finally, political will is especially important in this age of geopolitical, economic, and agency flux. This post–Cold War era, unlike the earlier periods reviewed in Chapter 2, makes it more difficult for nations to identify space as part of a few, broad national goals and necessitates even greater attention to the overarching principles laid out above. If steps toward improved procedures and communications are set in place now, they can be a catalyst for maximizing the scientific, economic, and programmatic success of cooperative activities for decades to come.

APPENDIXES

A

Cooperative U.S.-European Space Projects

Tables A.1 through A.3, although fairly comprehensive, substantially understate the amount of cooperation in space projects that has taken place between Europe and the United States.[1] This is because the tables do the following:

- Indicate none of the many principal investigator (PI)–coinvestigator collaborations that have been established in both directions across the Atlantic;
- Include no sounding rocket, balloon-borne, or aircraft-based experiments, which have been extensive with some countries;
- Present no data sharing arrangements, for example, between two principal investigators flying scientific instruments on the same or different spacecraft;
- Include no ground-based activity, such as the prearranged readout of scientific data by one country or institution of another's satellite data or the acceptance by one country of principal investigator/research investigations from another country to use data provided by the first Earth Resources Techonology Satellite (ERTS, now Landsat);
- Present no cooperation in technology or applications development, for example, on heat pipes (Shuttle Palette Satellite [SPAS]-01), spacecraft electrostatic charging and discharging (EOIM—Evaluation of Oxygen Interaction with Materials), Search and Rescue Satellites (COSPAS-SARSAT), or tether satellite experiments;
- Indicate none of the cooperative strategic-level planning and more detailed coordination that goes on between and among research organizations in all three discipline areas—for example, to indicate only one of many, through CEOS (Committee on Earth Observation Satellites); or
- Include no observing time on one another's astronomy satellites (U.S. responses to the European Space Agency [ESA] Announcements of Opportunity [AOs]; European responses to the National Aeronautics and Space Administration [NASA] AOs).

NOTE: The following abbreviations are used for European countries:

A	Austria
B	Belgium
CH	Switzerland
D	Germany
DK	Denmark
E	Spain
F	France
FI	Finland
GB	United Kingdom
GR	Greece
I	Italy
IRL	Ireland
L	Luxembourg
N	Norway
NL	Netherlands
P	Portugal
S	Sweden

TABLE A.1 U.S.-European International Cooperative Spacecraft Experiments in Earth Science from Space

Launch Year	Mission Name	Cooperating Countries	Experiment or Space Science Objectives
1964	Ariel-II	GB[a]-US	Measuring atmospheric ozone
1965	OGO-2	F[b]	Photometer to measure airglow
1966	OGO-3 (POGO)	F[b]	See OGO-2
1967	Ariel-III	GB[a]-US	Measure vertical distribution of molecular oxygen in Earth atmosphere
1967	OGO-4	F[b]	See OGO-2
1968	GEOS	D[b]	Determine size and shape of Earth and conduct gravitational field studies
1969	OGO-6	F[b]	Measure altitude distribution and width of atomic oxygen line in airglow and aurora
1970	Nimbus-4	GB[b]	Selective chopper radiometric temperature probe
1971	EOLE	F[a]-US	French satellite to study meteorological data in the Southern Hemisphere
1971	BIC	D[a]-US	Electric and magnetic cloud probe field studies
1972	NIMBUS-5	GB[b]	See NIMBUS-4
1975	NIMBUS-6	GB[c]-F[c]	Upper atmospheric sounding; random-access measurement system
1975	Atmospheric Explorer	GB[b]	Airglow photometer
1978	TIROS-N	GB[b]-F[b]	Atmospheric sounding radiometer; Advanced Research and Global Observations Satellite flew on eight satellites in the TIROS-N series
1978	NIMBUS-7	GB[b]-F[b]	Radiometer for atmospheric and mesospheric sounding; ARGOS[c]
1983	STS-9/Spacelab-1	ESA[d]-D[b]-US	Microwave remote-sensing experiment and metric camera for Earth observations (2)
1990	CRRES	D[b]	Study of Earth's magnetic fields
1991	STS-40/UARS	UK[b]-US	Upper atmospheric observations
1992	TOPEX-POSEIDON	F-US	Joint Centre National d'Études Spatiales–National Aeronautics and Space Administration mission to study relationship between Earth's oceans and climate
1992	LAGEOS-2	I-US	Improve geodetic reference datum (geoid) and Earth orientation, and measure crustal deformation, secular variation in Earth's gravity field, and wandering of Earth's polar axis and Earth rotation variations
1992	Eureca-1	ESA-US	Several Earth science experiments
1992	STS-45/ATLAS-1	B[b]-F[b]-D[b]-US	ATLAS 1-3: three missions to study the middle atmosphere and its variations
1993	STS-55/Spacelab D2	ESA-D[b]-US	Modular optoelectric multispectral scanner used to study atmospheric variations; also flown on two SPAS flights
1993	STS-56/ATLAS-2	B[b]-F[b]-D[b]-US	ATLAS 1-3: three missions to study the middle
1994	STS-66/ATLAS-3	B[b]-F[b]-D[b]-US	atmosphere and its variations
1994	STS-66/CRISTA-SPAS	D-US	Combined experiment with ATLAS-3 to study atmospheric variability
1994	STS-59/SRL-1	US-D[b]-I[b]	X-SAR as part of SIR-C
1994	STS-68/SRL-2	US-D[b]-I[b]	X-SAR as part of SIR-C
1997	STS-85/CRISTA-SPAS II	D-US	Experiments using CRISTA and MAHRSI instruments to study middle atmosphere and lower thermosphere

NOTE: Where countries are listed without a superscript notation (e.g., D-US), the mission was fully cooperative with many joint experiments and mission elements.

[a] Launch on a U.S. vehicle.
[b] European experiment on a NASA mission.
[c] Subsequent satellites in the NIMBUS series.
[d] In 1975, ESRO became ESA.

ARGOS	French satellite data collection system (Advanced Research and Global Observations Satellite)
ATLAS	Atmospheric Laboratory for Applications and Science
CRISTA	Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere
CRRES	Combined Release and Radiation Effects Satellite
GEOS	Geostationary satellite
LAGEOS	Laser Geodynamics Satellite
MAHRSI	Middle Atmosphere High-Resolution Spectrograph Investigation
NIMBUS	NASA environmental research satellite series
OGO	Orbiting Geophysical Observatory
POGO	Polar Orbiting Geophysical Observatory
SIR	Shuttle Imaging Radar
SPAS	Shuttle Pallet Satellite (Germany)
SRL	Space Radar Laboratory
STS	Space Transportation System (U.S.)
TIROS	Television Infrared Observing Satellite
TOPEX	(Ocean) Topography Experiment
UARS	Upper Atmospheric Research Satellite
X-SAR	X-band Synthetic Aperture Radar

TABLE A.2 U.S.-European International Cooperative Space Flight Experiments in Microgravity Research and Life Sciences

Launch Year	Mission Name	Cooperating Countries	Experiment or Space Science Ojectives
1972	Apollo 16	D[a], F[a]	Effect of exposure to heavy-nuclei cosmic radiation on biological specimens on Biostack facility
1972	Apollo 17	F[a], D[a]	Effect of exposure to heavy nuclei cosmic radiation on biological specimens on Biostack facility
1973	Skylab	B[a]	Space Manufacturing Experiment
1975	ASTP	F[a]	Effect of exposure to heavy nuclei cosmic radiation on biological specimens on Biostack facility
1983	STS-7/OSTA-2	D[a]	Formation of metal alloys in space on SPAS-01; materials science experiments on MEA-MAUS; social behavior of an ant colony in microgravity on GAS
1983	STS-9/Spacelab-1	ESA-D[a]-US	Multiple microgravity research (39) and life sciences (16) experiments
1984	STS 41-B	D[a]	SPAS-01A (Not deployed due to an RMS malfunction)
1984	STS-41C/LDEF	D[a]-IRL[a]-ESA[a]-CH[a]-GB[a]	Multiple experiments to determine the effects of space environment on materials
1985	STS-51B/Spacelab 3	F[a]-D[a]	Life science experiments in RAHF
1985	STS-51-G	F[a]-D[a]	Biomedical experiments plus two French life sciences experiments; three German GASs
1985	STS-61A/Spacelab-D-1	D-US[b]-ESA	76 microgravity research and life science experiments, including MEA and vestibular sled
1991	STS-40/SLS-1	CH[a]	Study of lymphocyte proliferation in weightlessness
1992	STS-42/Spacelab IML-1	ESA[a]-D[a]	Numerous life and materials science experiments using Biorack, Biostack, Cryostat, GPPF, and CPF to study cellular behavior, plant and human physiology, crystal growth, radiation environment, and critical point physics (also 10 GASs)
1992	STS-50/USML-1	ESA[a]	Protein and combustion experiments
1992	STS-46/Eureca-1 (launch)	ESA[c]-US	Mainly materials science, solar, and Earth science experiments
1992	STS-52/USMP-1	F[a]	Study of role of gravity-driven convection during solidification of materials on MEPHISTO facility
1993	STS-55/Spacelab D-2	D-US[b]-ESA	Multiple microgravity and life science experiments, including MAUS
1994	STS-62/USMP-2	F[a]	Study of the role of gravity-driven convection during the solidification of materials on the MEPHISTO facility
1994	STS-65/IML-2	ESA[a]	Numerous international life and materials science experiments using Biorack, Biostack, CPF, BDPU, TEMPUS, FFEU, APCF, and CPCG facilities (among others) to study cellular behavior, radiation environment, human physiology, surface forces materials processing, critical point physics, and crystal growth
1995	STS-73/USML-2	ESA-D[a]	Protein crystal growth experiments on APCF
1996	STS-75/USMP-3	F[a]	Study of role of gravity-driven convection during solidification of materials on MEPHISTO facility
1996	STS-76 (MIR 3)	ESA-US	Biology experiments on Biorack
1996	STS-77	D[a]	CFZF experiment
1996	STS-78/LMS	ESA[a]-F[a]	18 international microgravity experiments using AGHF, APCF, BDPU, and MMA facilities to study protein crystallization, materials processing, fluid dynamics, and microgravity environment; 16 life science experiments in musculoskeletal, cardiopulmonary, metabolic, behavior and performance, neuroscience, and space biology disciplines

1997	STS-83/MSL-1 STS-94 (MSL-1 reflight)	D[a], ESA[a]	Experiments in materials processing, combustion, mixing, and diffusion using TEMPUS, Combustion Module-1, DCE, CSLM, and Large Isothermal Furnace facilities
1998	STS-90 (Neurolab)	F-ESA-D-Canada-Japan	26 experiments in life sciences that focus on the nervous system, including neurobiology, sensory motor and performance functions, sleep, the vestibular system, and the autonomic nervous system, among other activities

NOTE: Where countries are listed without a superscript notation (e.g., D-US), the mission was fully cooperative with many joint experiments and mission elements.

[a] European experiment on a U.S. mission.
[b] U.S. experiment on a European mission.
[c] U.S.-cooperative mission launched on a U.S. vehicle.

AGHF	Advanced Gradient Heating Facility
APCF	Advanced Protein Crystallization Facility
ASTP	Apollo-Soyuz Test Project
BDPU	Bubble, Drop, and Particle Unit
CFZF	Commercial Float Zone Furnace
CPCG	Commercial Protein Crystal Growth facility
CPF	Critical Point Facility
CSLM	Coarsening in Solid-Liquid Mixtures Facility
DCE	Droplet Combustion Experiment
EURECA	European Retrievable Carrier
FFEU	Free Flow Electrophoresis Unit
GAS	Get Away Special
GPPF	Gravitational Plant Physiology Facility
IML	International Microgravity Laboratory
LDEF	Long Duration Exposure Facility
LMS	Life and Microgravity Spacelab
MAUS	Materialwissenschaftliche Autonome Experimente unter Schwerelosigkeit
MEA	Materials Experiment Assembly
MEPHIS	Material pour l'Étude des Phenomenes Interessant de la Solidification sur Terre et en Orbit
MMA	Microgravity Measurement Assembly
MSL	Microgravity Science Laboratory
OSTA	Office of Space Technology and Applications (NASA)
RAHF	Research Animal Holding Facility
SLS	Spacelab Life Sciences
SPAS	Shuttle Pallet Satellite (Germany)
STS	Space Transportation System (U.S.)
TEMPUS	Electromagnetic Containerless Processing Facility
TVD	Torque Velocity Dynamometer
USML	U.S. Microgravity Laboratory
USMP	U.S. Microgravity Payload

TABLE A.3 U.S.-European International Cooperative Ventures in Space Sciences

Launch Year	Mission Name	Cooperating Countries	Space Science Ojectives or Remarks
1962	Ariel-I	GB[a]-US	Measure energy spectrum of cosmic rays and solar x-rays
1964	Ariel-II	GB[a]-US	Measure galactic radio noise and micrometeoroid flux
1964	Explorer 20	GB[b]	Measure ion mass composition and temperature
1964	San Marco-I	I[a]-US	Atmospheric physics; launched from Wallops by Italian launch crew
1965	Explorer 31 DME-A	GB[b]	Measure ion mass composition and temperature, and electron temperature
1965	FR-1	F[a]-US	Study very low frequency wavefields in magnetosphere and irregularities in ionosphere
1965	OSO-2	GB[b]-F[b]	Conduct multiple solar research experiments
1967	San Marco-II	I[a]-US	Ionospheric propagation studies; first launch from San Marco platform
1967	Ariel-III	GB[a]-US	Multiple atmospheric physics measurements
1967	OSO-4	GB[b]	Measure distribution of total solar x-ray emissions
1967	Pioneer-8	I[b]	Flux gate magnetometer
1968	OGO-5	GB[b]-F[b]-NL[b]	Determine direction of incidence of primary cosmic rays and density or temperature of hydrogen in geocorona; measure energy spectrum of cosmic-ray electrons
1968	ESRO-2 (IRIS)	ESRO[a]-US	Study solar x-rays and cosmic radiation in Van Allen belt
1968	ESRO-1A (Aurorae)	ESRO[a]-US	Measure particles impinging on polar ionosphere
1968	HEOS-1	ESRO[a]	Study interplanetary magnetic fields and cosmic-ray particles
1969	OSO-5	F[b]-GB[b]	Measure solar x-ray flux and self-reversal of Lyman-Alpha line
1969	Apollo 11	CH[b]	Measure composition of solar wind
1969	OSO-6	I[b]-GB[b]	Study solar helium I and helium II resonance radiation
1969	ESRO-1B (Boreas)	ESRO[a]	Study ionospheric and auroral phenomena (polar orbiter)
1969	GRS-A (Azur-1)	D[c]-US	Study of inner Van Allen belt and auroral zones
1969	Apollo 12	CH[b]	Measure composition of solar wind
1970	Explorer 42	I	First x-ray satellite, Scout launched from San Marco platform
1971	Apollo 14	CH[b]	Measure composition of solar wind
1971	San Marco-III	I[c]-US	Study local density of equatorial upper atmosphere, San Marco launch
1971	Apollo 15	CH[b]	Measure composition of solar wind
1971	Explorer 45	I[b]	Study of inner magnetosphere; San Marco launch
1971	Ariel-IV	GB[a]-US	Measure VLF radiation and cosmic radio noise
1972	HEOS-2	ESRO[a]	Investigate particles and micrometeorites in space
1972	Pioneer 10	D[b]-US	Investigation of Jupiter and interplanetary medium
1972	TD-1	ESRO[a]	Study high-energy emissions from stellar and galactic sources
1972	Apollo-16	CH[b]	Measure composition of solar wind
1972	Explorer 46	D[b]	Cosmic dust detectors on Meteoroid Technology Satellite
1972	OAO-3	GB[b]	Study stellar ultraviolet (UV) and x-ray emissions
1972	Explorer 48	I-US	Small astronomy satellite to study gamma rays; San Marco launch
1972	ESRO-4	ESRO[a]	Investigate ionosphere, magnetosphere; auroral and solar particles
1972	Aeros	D[a]-US	Measure solar extreme UV and correlate with upper-atmosphere components
1973	Skylab	F[b]-CH[b]	Sky survey, distribution of galaxies and ionized hydrogen; solar wind analysis

1973	Pioneer 11	D[a]-US	Investigation of Jupiter, Saturn, and interplanetary medium
1974	San Marco-C-2	I[a]-US	Measure equatorial neutral atmospheric density, composition, and temperature
1974	Aeros B-2	D[a]	Study state and behavior of upper atmosphere and ionosphere
1974	ANS	NL[a]-US[b]	UV photometry and measuring soft and intermediate-energy x-ray emissions
1974	UK-5/Ariel-5	GB[a]-US-I	Conduct x-ray sky survey; launched from San Marco
1974	INTASAT	E[a]-US	Conduct ionospheric total electron counts
1974	Helios-A	D[a]-US-I-A	Study the Sun from heliocentric orbit
1975	Explorer 53 (SAS-3)	I	Study x-ray sources within and beyond Milky Way galaxy, San Marco launch
1975	OSO-8	F[b]-GB[b]	Spectrographic study of solar chromosphere; x-ray heliometer
1975	COS-B	ESA[a]	Cosmic-ray satellite to study extraterrestrial gamma radiation
1976	Helios-B	D[a]-US-I-A	Measure micrometeoroid flux; study solar x-rays and planetary orbits
1977	Voyager 2	F[b]-D[b]-US	Investigation of Jupiter and Saturn planetary systems and interplanetary medium
1977	SIRIO	I[a]	Investigate trapped radiation flux, magnetic field intensity, and electron energy
1977	Voyager 1	F[b]-D[b]-US	See Voyager 2
1977	ISEE-1/2 (Dual Payload)	ESA[a]-US-F	Coordinated spacecraft studies of magnetosphere, interplanetary space, and their interaction; three coordinated spacecraft missions (see ISEE-3)
1978	IUE-A	ESA-US-GB	UV spectroscopy of stellar objects, gas clouds, planets, and comets
1978	Pioneer-Venus 1 Orbiter	GB[b]-D[b]-ESA[b]-US	Atmospheric, ionospheric, solar-wind interaction; studies of Venus
1978	GEOS-B	ESA[a]	Studies of magnetosphere
1978	Pioneer-Venus-2	F[b]-US	Atmospheric and cloud studies at Venus
1978	ISEE-3	D[b]-F[b]-NL[b]-CH[b]-GB[b]-ESA[b]	Solar-wind composition and mapping, comet flyby
1979	UK-6	GB[a]	Study of ultra heavy and low-energy cosmic rays
1979	HEAO-3	DK[b], F[b]	Study isotopic composition and atomic number of cosmic nuclei
1980	SMM	NL[b]-GB[b]-D[b]	Solar hard x-ray imaging spectrometry
1983	IRAS	NL[a]-US[b]-GB	Conduct infrared all-sky survey
1983	EXOSAT	ESA[a]	Continuous observations of x-ray sources; U.S. experiment on board
1983	Spacelab 1	ESA-US	Astronomy and physics (6); space plasma physics (5)
1984	LDEF	D[b]-DK[b]-IRL[b] ESA[b]-CH[b]-GB[b]	Broad-scale investigations of space environment
1984	AMPTE	D[b]-GB[b]-US	Identify particle entry windows and energizing or transport processes in magnetosphere (artificial comets)
1985-1986	International Halley Watch (Giotto)	ESA-USSR-Japan-US	Spacecraft and mission design coordinated for ESA's Giotto, USSR's Venera-Halley (2), and Japan's Planet-A; U.S. coordinated ground-based and near-Earth observations and Deep Space Network
1985	Spacelab 3	F[b]	Very Wide Field Camera (astrophysics)
1985	Spacelab 2	ESA[b]-GB[b]	Flew ESA-developed IPS; hard x-ray imaging (GB) and coronal helium abundance experiments (GB)
1988	San Marco-IV	I[a]-US-D	Effects of solar activity on meteorological processes
1989	Magellan	F[b]	Study of Venus's gravity and atmospheric tides
1989	Hipparcos	ESA-US[b]	Strong international cooperation on spacecraft emergency operations post launch
1989	Galileo	D-US	Multidisciplinary studies of Jupiter system, its moons, atmosphere, and magnetosphere
1990	HST	ESA-US	High-resolution coverage of optical and UV wavelengths
1990	ROSAT	D[a]-US[b]-GB	X-ray sky survey and sources study
1990	Ulysses	ESA[a]-US[b]	Observations of solar and interplanetary medium out of plane of ecliptic
1991	GRO	ESA[b]-D[b]-NL[b]	Wide-range gamma-ray detection; imaging Compton telescope
1992	STS-45	F[b]	FAUST reflight
1992	Eureca-1	ESA-US[b]	X-ray science instrument

(continued)

TABLE A.3 Continued

Launch Year	Mission Name	Cooperating Countries	Space Science Ojectives or Remarks
1992	Mars Observer	F[b]-US	Mars geoscience and climatology
1993	ORFEUS-SPAS-1	D-US	Explore universe in far and extreme UV
1994	Wind	ESA[b]-US-F(3) [b]	Measure three-dimensional plasma and energetic particle distributions
1995	SOHO	US[b]	Investigate processes that lead to formation and heating of solar corona
1996	FAST	D[b]	Study energy transfer processes in magnetosphere
1996	ORFEUS-SPAS-2	D-US	Second flight of this German-U.S. cooperative, Shuttle-launched subsatellite
1996	TSS-IR (reflight)	I[a]-US[b]	Experiments on electricity in space
1997	Cassini-Huygens	US-ESA-I	Spacecraft orbiter and probe mission to Saturn and its moon, Titan
1997	Equator-S	D[c]	Measure magnetic and electrical fields and density, velocity, temperature, and composition of the charged particles surrounding the spacecraft

NOTE: Where countries are listed without a superscript notation (e.g., D-US), the mission was fully cooperative with many joint experiments and mission elements.

[a] Reimbursable launch on a U.S. vehicle; U.S.-cooperative mission launched on a U.S. vehicle.
[b] European experiment on a U.S. mission.
[c] U.S. experiment on a European mission; ESRO became ESA in 1975.

AMPTE	Active Magnetospheric Particle Tracer Explorer
ANS	Astronomical Netherlands Satellite
COS	Cosmic Ray Satellite (Germany)
DME	Direct Measurement Explorer
ESRO	European Space Research Organization
FAST	Fast Auroral Snapshot Explorer
FAUST	Far Ultraviolet Space Telescope
GEOS	Geostationary satellite
GRO	Gamma-Ray Observatory
GRS	German Research Satellite
HEAO	High Energy Astronomical Observatory
HEOS	Highly Eccentric Orbit Satellite
HST	Hubble Space Telescope
INTASAT	Instituto Nacional de Tecnica Aerospacial Satellite
IRAS	Infrared Astronomical Satellite
ISEE	International Sun-Earth Explorer

IUE	International Ultraviolet Explorer
OAO	Orbiting Astronomical Observatory
OGO	Orbiting Geophysical Observatory
ORFEUS	Orbiting and Retrievable Far and Extreme Ultraviolet Spectrometer
OSO	Orbiting Solar Observatory
ROSAT	Roentgen Satellite
SIRIO	Italian Satellite for Industrially Oriented Research
SMM	Solar Maximum Mission
SOHO	Solar and Heliospheric Observatory
STS	Space Transportation System (U.S.)
TD	Thor Delta
TSS	Tethered Satellite System
VFL	Very low frequency

SOURCE: Update of Table 9-1, U.S. Congress, Office of Technology Assessment, in *International Cooperation and Competition in Civilian Space Activities,* OTA-ISC-239, U.S. Government Printing Office, Washington, D.C., July 1985, p. 379.

B

Letter from the National Aeronautics and Space Administration to the Enrico Fermi Institute, University of Chicago, August 11, 1972

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

August 11, 1972

OFFICE OF THE ADMINISTRATOR

Dr. John A. Simpson
The Enrico Fermi Institute
University of Chicago
933 East 56th Street
Chicago, IL 60637

Dear Dr. Simpson:

Your letter of 11 July 1972 to Dr. Fletcher has been referred to me. Your arguments for committing Pioneer H to an out-of-the-ecliptic mission are well taken and very persuasive. The relatively low cost of such a mission, since the Pioneer H spacecraft is a spare for Pioneers 10 and G, and the considerable scientific value to be derived, argue very strongly in favor of the mission. In fact, this kind of mission was described to the Space Science Board 1971 Woods Hole Summer Study by our Science Advisory Group. Moreover, on 15 June 1972 our Outer Planets Science Advisory Group presented to NASA management their recommended strategy for exploring the outer planets, in which the Pioneer H out-of-the-ecliptic mission was an important item.

On the other hand, there are other considerations that argue against committing to this mission at the present time. Quoting from the Woods Hole Summer Study referred to earlier:

> "The radiation belt of Jupiter constitutes a hazard of undetermined magnitude for close-in Jupiter flybys, orbiters, and entry probes. We recommend that Pioneers F and G be utilized to evaluate the radiation environment of Jupiter as fully as possible, even at the risk of possible disablement of the spacecraft, and that Pioneer H be held in readiness for use as a Jupiter magnetosphere mission for further evaluation of the radiation hazard if it has not been clarified by Pioneers F and G. This will permit the choice of safe trajectories for both Grand Tour missions and those for the more intensive study of Jupiter. Studies of instrument design for Pioneer H to operate in a high-intensity radiation environment should also be started soon in case such hardened instrumentation should turn out to be the only solution for Jupiter exploration conducted within its radiation belt."

2

NASA agrees that we must determine the radiation environment of Jupiter in order to support the overall outer planets exploration strategy that has been proposed to us by a majority of the planetary scientists working with us. Although Pioneer 10, presently on its way to Jupiter, is still working well, we cannot assume that it will give us all the definitive information on the radiation environment of Jupiter that is required. Nor, can we be certain that the combination of Pioneers 10 and G will complete the task. Thus, to determine Jupiter's radiation environment adequately to plan and design orbiter and probe missions to Jupiter, it seems prudent to hold Pioneer H as a backup for this very vital objective.

Later, if Pioneers 10 and G have given us sufficient information for planning and designing the further investigation of Jupiter, we can then reconsider the use of Pioneer H for other attractive missions that various scientists have urged NASA to undertake. Since there are many such missions, we will again have to make a choice, and your arguments for the out-of-the-ecliptic mission will be of considerable assistance in deciding, and we greatly appreciate having your recommendations. Because of your interest, we will keep you informed. In the meantime, my very best regards and sincere thanks for your thoughts.

Sincerely,

Homer

Homer E. Newell
Associate Administrator

C

Memorandum of Understanding Between the United States National Aeronautics and Space Administration and the European Space Agency for the International Solar Polar Mission, March 29, 1979

MEMORANDUM OF UNDERSTANDING BETWEEN THE UNITED STATES NATIONAL AERONAUTICS AND SPACE ADMINISTRATION AND THE EUROPEAN SPACE AGENCY FOR THE INTERNATIONAL SOLAR POLAR MISSION

ARTICLE 1 - Purpose

The United States National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA), desiring to extend the fruitful cooperation developed in previous joint space projects, affirm their mutual interest in carrying out a further cooperative spacecraft project for peaceful scientific purposes. Accordingly, NASA and ESA will undertake a cooperative project, to be known as the International Solar Polar Mission (hereinafter referred to as the ISPM project), to send two instrumented spacecraft far out of the ecliptic plane of the solar system to conduct coordinated observations of the interplanetary medium and the Sun simultaneously in the northern and southern hemispheres of the solar system.

ARTICLE 2 - Mission

(1) The primary objectives of the scientific mission will be to investigate, at the various solar latitudes out of the ecliptic plane of the solar system, the properties of the solar corona, the solar wind, the structure of the Sun-wind interface, the heliospheric magnetic field, solar and non-solar cosmic rays, and the interstellar/interplanetary neutral gas and dust. Secondary objectives of the mission include interplanetary physics investigations during the initial Earth-Jupiter phase, when the separation of the two spacecraft will be approximately 0.01 astronomical unit, and measurements of the Jovian magnetosphere during the Jupiter flyby phase.

(2) The ISPM project involves the planned dual launching in early 1983 of the two spacecraft - one developed by NASA and the other by ESA - by the Space Transportation System (STS) on a single space shuttle mission with an Inertial Upper Stage (IUS) of suitable configuration. The two spacecraft, which will separate shortly after launch, will be directed towards Jupiter so that after Jovian encounter, one spacecraft will be carried out of the ecliptic plane into the northern solar

system hemisphere in an elliptical orbit around the Sun, and the other spacecraft into the southern hemisphere. Both spacecraft will recross the plane of the ecliptic in their trajectories around the Sun. The planned duration of the mission from launch until passage of each spacecraft over both solar poles is approximately four and one-half years.

ARTICLE 3 - Selection of and Arrangements for Investigations

(1) Following the coordinated NASA/ESA selection of investigations, the final experiment complement of the two spacecraft was established by mutual agreement between the NASA Associate Administrator for Space Science and the responsible ESA Director. Any changes in the scientific scope of the selected experiments or to the final experiment complement will be established by mutual agreement between the NASA Associate Administrator for Space Science and the ESA Director of Scientific Programs.

(2) In regard to the furnishing of the payloads of their respective spacecraft, ESA and NASA will make direct arrangements with the selected Principal Investigators, their institutions or their funding authorities, as determined by each agency's procedures.

ARTICLE 4 - NASA Responsibilities

To carry out this project, NASA will use its best efforts to:

(a) carry out mission analysis and design jointly with ESA;

(b) design, fabricate, integrate and test one of the two spacecraft (hereinafter called the NASA spacecraft);

(c) provide all U.S. origin scientific instrumentation and documentation for both spacecraft, as jointly agreed pursuant to Article 3(1), in accordance with the jointly agreed schedule as described in the mutual interface document;

(d) integrate into its spacecraft the scientific instruments as jointly agreed pursuant to Article 3(1);

(e) conduct, as appropriate with ESA prior to launch, radio frequency data tests to ensure compatibility of the NASA spacecraft with the ground network interface, with the Deep Space Network, and with the Tracking and Data Relay Satellite System, if support is required by the project;

(f) mate and test the two spacecraft for launch, jointly with ESA;

(g) integrate the two mated spacecraft with the Space Shuttle and IUS vehicles;

(h) provide all launching services for the two mated spacecraft by a Space Shuttle with IUS of suitable configuration together with necessary ground support equipment;

(i) conduct all in-orbit operations of its spacecraft;

(j) provide tracking and data acquisition support by the NASA Deep Space Network stations;

(k) provide control center facilities and personnel during the mission lifetime, and accommodate ESA control center personnel as mutually agreed;

(l) process and distribute to all principal investigators and to ESA acquired data in a format to be mutually agreed, and provide all data records of the ESA spacecraft to ESA;

(m) provide such information in a mutually agreed form as ESA may need to prepare operational software for its spacecraft;

(n) provide Radioisotope Thermoelectric Generators, suitable simulators and associated ground support equipment to ESA for its spacecraft; and

(o) provide technical advice and consultation, as mutually agreed.

ARTICLE 5 - ESA Responsibilities

To carry out this project, ESA will use its best efforts to:

(a) carry out mission analysis and design, jointly with NASA;

(b) design, fabricate, integrate and test one of the two spacecraft (hereinafter called the ESA spacecraft);

(c) provide its own scientific instrument and documentation, as jointly agreed pursuant to Article 3(l), in accordance with the jointly agreed schedule as described in the mutual interface document;

(d) integrate into its spacecraft the scientific instruments as jointly agreed pursuant to Article 3 (l);

(e) deliver the spacecraft, together with necessary ground support equipment, to a designated site in the United States for integration with the NASA spacecraft in accordance with the schedule described in the mutual interface document;

(f) conduct, as appropriate with NASA prior to launch, radio frequency data tests to ensure compatibility of the ESA spacecraft with the ground network interface, with the Deep Space Network, and with the Tracking and Data Relay Satellite System if support is required by the project;

(g) mate and test the two spacecraft for launch, jointly with NASA;

(h) provide personnel for duty at the NASA control center for control of the ESA spacecraft, and meet all incremental costs to NASA for extraordinary control center operations which ESA may request to control or manage its spacecraft, as agreed in the mutual interface document; and

(i) provide technical advice and consultation, as mutually agreed.

In addition ESA will be responsible for decision making for all in orbit operations of the ESA spacecraft.

ARTICLE 6 - Management

(1) Each Agency will designate a Project Manager. The Project Manager will be responsible for coordinating the responsibilities of each Agency under this Memorandum of Understanding with respect to the other. They will co-chair an ISPM Joint Working Group (JWG), which will monitor the project and constitute the principal interface between the scientific and technical requirements of the mission. The JWG will meet at least twice a year. In principle, such meetings will be scheduled equally in the U.S. and in Europe.

(2) The two Project Managers will prepare and approve the NASA/ESA ISPM mutual interface document. This document will contain interface requirements, references to necessary documentation and software, delivery schedules, mated or joint test plans, and such other technical information as the Project Managers deem to be necessary.

(3) The Project Managers will also decide all issues where this Memorandum of Understanding calls for mutual agreement. If they are unable to come to an agreement on a particular issue, the issue will be resolved by mutual agreement between the NASA Director of Solar Terrestrial Programs and the

responsible ESA official. If agreement is not reached, the matter will be referred to the NASA Associate Administrator for Space Science and the ESA Director of Scientific Programs. Should the latter be unable to resolve the issue, the provisions of Article 18 will apply.

(4) Each agency will designate a Project Scientist who will represent all investigators participating in the project, maintain close liaison with his respective counterpart and ensure the compatibility of the overall mission with the scientific objectives. The two Project Scientists will be members of the JWG.

ARTICLE 7 - Flight Readiness

Final determination of the readiness of the two spacecraft for launching will be a joint decision of ESA and NASA based on an agreed series of reviews as described in the mutual interface document. Such reviews will be conducted by each Agency for its respective spacecraft with agreed representation from the other Agency. The final flight readiness review of the two mated spacecraft will be conducted by a joint panel with co-chairmen designated by the NASA Associate Administrator for Space Science and the ESA Director of Scientific Programs.

ARTICLE 8 - Launch Vehicle Interfaces

(1) In view of NASA's responsibilities for integration and operation of the STS, the NASA Project Manager will be responsible for ensuring that the dual spacecraft and scientific instruments conform with all STS payload accommodation and safety requirements. The requirements and standards, including any waivers thereto, will be referenced as part of the mutual interface document.

(2) ESA will ensure that its spacecraft including payload instruments conform to STS payload accommodation and safety requirements. NASA will assure internal conformance with the STS payload accommodation and safety requirements for the items provided under Article 4.

(3) The Project Managers will supply to each other such documentation as is necessary to carry out their tasks in this respect.

ARTICLE 9 - Scientific Working Team

An ISPM Scientific Working Team (SWT) will be established under the co-chairmanship of the two Project Scientists. Principal Investigators of on-board experiments and of theoretical and interdisciplinary investigations, plus the radio science Team Leader, will be members of the SWT. Its purpose will be to assist the JWG in implementing the scientific objectives of the Project, to coordinate exchange of data among all ISPM investigators, and to facilitate the contribution of data from the mission to interplanetary, solar and Jovian studies. The SWT will meet at appropriate intervals during the lifetime of the mission, both before and after launch. In principle, such meetings will be scheduled equally in the U.S. and Europe.

ARTICLE 10 - Data Rights and Distribution

First publication rights to data obtained from a Principal Investigator's instrument will reside with the Principal Investigator for one year from receipt of processed data and necessary spacecraft information in a form to be recommended by the SWT and to be agreed by the JWG prior to launch. Arrangements for provision of such data to Principal Investigators of the theoretical and interdisciplinary investigations will be recommended by the SWT for implementation by the JWG. Following the period of first publication rights, records or copies of reduced data will be deposited in the U.S. National Space Science Data Center (NSSDC), with the Data Library of the European Space Operations Center (ESOC), and will be listed with the World Data Center for Rockets and Satellites. Such records will then be made available to interested scientists, upon reasonable request, by the World Data Center.

ARTICLE 11 - Publication of Results

Scientific results of the mission will be made available to the public through publication in appropriate scientific and technical journals and other established channels, and through publication of final engineering and scientific reports by NASA and ESA, to be placed in the NSSDC and the Data Library of ESOC. In the event that such reports or publications are copyrighted, ESA and NASA shall have a royalty-free right under the copyright to reproduce and use such copyrighted work for their own purposes.

ARTICLE 12 - Funding Arrangements

Each Agency will bear the full cost of discharging its respective responsibilities, including travel and subsistence for its own personnel and transportation charges on all equipment and flight hardware for which it is responsible.

ARTICLE 13 - Limits of Obligation

It is understood that the ability of NASA and ESA to carry out their obligations under this Memorandum of Understanding is subject to their respective funding procedures.

ARTICLE 14 - Customs Clearance and Visas

ESA and NASA will use their best efforts to arrange free customs clearance for all equipment required in this project. NASA will use its best efforts to facilitate the issuance of visas for ESA personnel including contractors and non-U.S. investigators participating in the project.

ARTICLE 15 - Public Information

Each Agency may release public information regarding its own portion of the project as desired and, insofar as the participation of the other Agency is concerned, after suitable coordination. Each Agency will assure that the extent of its participation in the project is appropriately recorded in still and motion photography and that such photography is made available to the other Agency for public information purposes in a format to be mutually agreed.

ARTICLE 16 - Liability

(1) NASA and ESA agree that, with respect to injury or damage to persons or property involved in STS operations undertaken pursuant to this Memorandum of Understanding, neither NASA nor ESA, nor any person who has contracted with ESA or NASA for STS services or owns property to be flown on the Shuttle, shall make any claim with respect to injury to or death of its own or its contractor's or subcontractor's employees or damage to its own or its contractor's or subcontractor's property caused by NASA, ESA or any other person involved in STS operations, whether such injury, death or damage arises through negligence or otherwise.

(2) In the event of damage to other persons or property, for which damage there is liability under international law or the principles of the Convention on International Liability for Damage Caused by Space Objects, NASA and ESA shall consult promptly on an equitable sharing of any payments that have been or may be agreed in settlement. If agreement is not reached within 180 days, the two Agencies will act promptly to arrange for early arbitration to settle the sharing of such claims following the 1958 model rules on arbitral procedure of the International Law Commission.

ARTICLE 17 - Patent Use - Authorization, Consent and Indemnification

(1) In order to avoid any possible interruption to the conduct of this cooperative project which might arise from patent infringement litigation in U.S. Courts, NASA hereby gives authorization and consent (without prejudice to any rights of indemnification) for all use and manufacture by ESA of any invention described in and covered by a patent of the United States in the performance of any obligations under this Memorandum of Understanding, including the performance of any such obligations by any contractor or subcontractor, providing such use and manufacture is confined entirely to the discharge of the obligations of this Memorandum of Understanding.

(2) In the event any liability is incurred by the U.S. Government for the practice of inventions covered by privately owned U.S. patents, either as royalties owed under an existing patent license inuring to the benefit of NASA or as judgment and litigation costs resulting from a suit for patent infringement in the U.S. Court of Claims, and such liability is incurred as a result of ESA's and/or any of its contractors' or subcontractors' performance of obligations under this Memorandum of Understanding, or as a result of NASA's use under this Memorandum of Understanding of the items furnished by ESA under this Memorandum of Understanding, ESA agrees to indemnify NASA or any other U.S. Agency against, and make reimbursement for, such royalties and/or costs. ESA shall provide such information and assistance as it has available in the defense of any such patent infringement suit brought in the U.S. Court of Claims.

ARTICLE 18 - Disputes

(1) Any disputes in the interpretation or implementation of the terms of this Memorandum of Understanding shall be referred to the NASA Administrator and the Director General of ESA for settlement.

(2) Should the NASA Administrator and the Director General of ESA be unable to resolve such disputes, they will, if Parties so agree, be submitted to such other form of resolution or arbitration as they will agree.

ARTICLE 19 - Amendments

Each party may propose to the other amendments to this Memorandum of Understanding in writing. Agreements on such amendments shall be established by the parties in the form of riders to this Memorandum of Understanding.

ARTICLE 20 - Entry into Force and Termination

This agreement shall enter into force on the date when both the NASA Administrator and ESA Director General have signed it, and shall remain in effect for a period of five years after launch of the ISPM spacecraft and for such additional periods as mutually agreed. The termination of the ISPM project will be mutually agreed by NASA and ESA.

For the National Aeronautics and Space Administration

For the European Space Agency

Date 3/29/79

Date 29.III.79.

D

Letter from the Office of Management and Budget to the National Aeronautics and Space Administration, June 22, 1981

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF MANAGEMENT AND BUDGET
WASHINGTON, D.C. 20503

JUN 2 [illegible] 1981

Honorable Alan M. Lovelace
Acting Administrator
National Aeronautics and
Space Administration
Washington, D.C. 20546

Dear Dr. Lovelace:

Thank you for your letter of April 24, 1981, regarding the International Solar Polar Mission, a joint space venture involving the European Space Agency and NASA. Your letter noted that the recent ESA proposal for NASA to buy a West German spacecraft for ISPM is scientifically acceptable, but that additional funds would be required in fiscal years 1983 to 1986. You asked for guidance on how to proceed.

A meeting was recently held between representatives of ESA and this office to discuss the future and funding for ISPM. The view was conveyed to ESA that due to further likely cost growth on the space shuttle and other space projects which would exacerbate the already difficult fiscal year 1983 situation, no add-on was possible for the ISPM. However, it was noted that NASA has the flexibility to reprogram funds from within budgetary resource levels to pursue projects within its overall priorities, particularly those that involve important international commitments.

I thank you for your views on this important matter.

Sincerely,

David A. Stockman
Director

E

NASA Presentation to NRC Committee for Its Study on "The International Solar Polar Mission (A Review of Assessment Options)," June 1981

The alternative mission plans considered and their estimated run-out costs as furnished by NASA (including all past year expenditures incurred for the U.S. spacecraft) are given below. The costs of launch vehicles, launch operations, data acquisition, flight operations, and tracking are not included in these estimates. According to NASA, these costs are approximately the same for either one or two spacecraft launched on a single Shuttle-Centaur and are estimated to be in the range of $175 million to $200 million.

Options		NASA-Estimated Costs ($ millions)
I	A single ESA spacecraft with the U.S. and European instruments currently assigned to it (NASA provides the launch vehicle and services for launch, mission control, tracking, data analysis for U.S. experiments, and data acquisition and storage for all experiments)	110-130
II	Procurement of a second ESA spacecraft by NASA at a fixed price of $40 million (FY 1981 dollars).[a] This second spacecraft would be equipped with the instruments planned for a NASA spacecraft except the solar imaging instruments on the despun platform, which cannot be accommodated. Adaptation of instruments to this spacecraft would be required and involves unknown costs.	235-250
III	Procurement of a U.S.-built NASA spacecraft with no imaging. The ESA spacecraft would be provided as planned; the second spacecraft would be U.S.-built and equipped with all planned instruments except the coronagraph and x-ray–extreme ultraviolet (XUV) telescope.	310-330
IV	Procurement of a NASA spacecraft with minimum imaging. This option is the same as "Option III" except for the addition of a spinning white light coronagraph on the NASA spacecraft, which potentially involves high development costs.	380-430
V	Full restoration of the two-spacecraft mission, including high-quality imaging capability (white light coronagraph and x-ray–XUV telescope) on a despun platform on the NASA spacecraft	410-460

NOTE: ESA = European Space Agency; NASA = National Aeronautics and Space Administration.

[a] ESA had made an offer to NASA to have the second spacecraft built by Dornier for $40 million, with ESA prepared to pay for any cost overrun.

F

Correspondence Between the European Space Agency and the National Aeronautics and Space Administration, October 12, 1994, to April 17, 1996

esa

european space agency
agence spatiale européenne

D/Sci/RMB/GC/val

Paris, 12 October 1994

Dr. Wesley T. Huntress, Jr.
Associate Administrator for Space
Science – Code SS
NASA Headquarters
Washington DC, 20546 0001
USA

Dear ~~Dr. Huntress~~ Wes,

Thank you for your prompt letter regarding the launch of SOHO. No doubt, the decision we took is the most rational one, and offers the best guarantees of success. The Project will comply with your request to inform the SOHO international team about the new date and explain the rationale behind it.

On another topic, as you may remember, during our meeting in Austria you promised to write me officially concerning Ulysses extension beyond 1995. I would myself be very happy with what you said, however, on 7–8 November 1994 we will have our next Science Programme Committee meeting and the SPC would like to be informed about the NASA position regarding the Ulysses mission extension. An official statement from you would help unblocking the funds for the extension.

I want to take this occasion to tell you how pleased I am that you could attend the Survey Committee meeting in Rome. I assume that Carl Pilcher told you how the meeting was concluded, much to the satisfaction of all participants. I also believe that you received the Information Note we prepared for the press after the meeting.

I should add that I am very happy that you appointed Carl to observer on behalf of NASA. He attended the whole meeting and gave a much appreciated personal contribution.
I am sure that in his new capacity of Executive Secretary to IACG Carl will be able to bring new life to the Group in this very important year 1995.

Yours sincerely,

Roger

Dr. R.M. Bonnet
Director of
Scientific Programme

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

Reply to Attn of: SS

NOV 3 1994

Dr. R. M. Bonnet
Director of Scientific Programs
European Space Agency
8-10 rue Mario-Nikis
75738 Paris Cedex 15
FRANCE

Dear Dr. Bonnet:

Thank you for your letter of October 12, 1994, requesting information about the NASA position regarding the Ulysses mission extension.

I am very pleased to report that barring any unforeseen circumstances that we will be able to continue the Ulysses mission through another set of polar passes. This extension offers the unique opportunity to observe the high-latitude behavior of the sun at solar maximum and to dramatically improve the database of gamma-ray burst locations. NASA intends to continue operating all missions that will continue to return new science, as long as we can do so while allowing a stimulating program of new missions and keeping within the budget constraints presented to us by the Administration and Congress. Since our budget is approved on an annual basis, we cannot make any guarantees. However, the Ulysses Maximum Mission is very high on our list of priorities, and the prospects look excellent for realizing its extension, provided NASA can maintain a healthy space science budget.

I congratulate you on the celebration activities and press coverage arranged by ESA during the Ulysses south polar pass in mid-September 1994. We need to continue building public support for our space science missions, and I expect NASA to take advantage of the north polar pass in September 1995 to reach out again to the public.

Sincerely,

Wesley T. Huntress, Jr.
Associate Administrator
for Space Science

esa

european space agency
agence spatiale européenne

Jean-Marie Luton
Director General

DELEGATION OF POWERS

I, Director General of the European Space Agency, legal representative, hereby delegate to Mr. R.M. Bonnet, Director of the the Scientific Programme, the full powers to sign, on behalf of the European Space Agency, the exchange of letters concerning the extension of the Ulysses mission.

Paris, 30 March 1995

J.M. Luton

esa

european space agency
agence spatiale européenne

JUR/302/WMT/MJ/2847

Paris, 31 MARS 1995

Dr. Wesley T. Huntress, Jr.
Associate Administrator for
Space Science - Code S
NASA Headquarters
Washington, DC 20546
USA

Dear Dr. Huntress,

Further to our correspondence on the possible extension of our cooperation in the Ulysses mission, I am pleased to propose that, in accordance with Article 20 of the Memorandum of Understanding between NASA and ESA on the International Solar/Polar mission, signed on 29 March 1979, this Memorandum be extended for a duration of one solar orbit, i.e. six years and three months.

If you agree with this proposal, I suggest that this letter, together with your positive reply, constitute an amendment to the above-mentioned Memorandum of Understanding.

The amendment will enter into force on the date of your positive reply.

Yours sincerely,

R. Bonnet
Director of the Scientific Programme

National Aeronautics and
Space Administration

Office of the Administrator
Washington, DC 20546-0001

MAR 21 1996

TO: I/Associate Administrator for External Relations

FROM: A/Administrator

SUBJECT: Delegation of Authority to Extend Memorandum of Understanding Governing Ulysses Mission

I hereby authorize you to act on my behalf in responding to the request of the Associate Administrator for Space Science to extend the Memorandum of Understanding (MOU), signed in 1979 by NASA and the European Space Agency (ESA), governing the Ulysses mission. I understand that the Associate Administrator for Space Science plans to proceed with up to six successive yearly extensions of the Ulysses MOU.

Daniel S. Goldin

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

Reply to Attn of: IRD

APR 11 1996

Dr. Roger Bonnet
Director of the Scientific Programme
European Space Agency
8-10 rue Mario-Nikis
75738 Paris Cedex 15
FRANCE

Dear Dr. Bonnet:

In response to your March 31, 1995, letter to Dr. Huntress on behalf of Mr. Luton, I am pleased to extend the NASA-ESA Memorandum of Understanding (MOU) for Ulysses.

However, NASA plans to proceed by the conclusion of six successive yearly renewals, governed by Articles 13 and 20 of the NASA-ESA MOU for Ulysses. If either side has the intention of terminating the MOU, it will endeavor to notify the other at least six months before the following yearly renewal.

I propose that this letter, along with the MOU signed in 1979, your letter of March 31, 1995, and your affirmative reply to this letter, constitute our agreement to extend the Ulysses mission.

I look forward to continued cooperation between our two agencies.

Sincerely,

John D. Schumacher
Associate Administrator for
External Relations

esa

european space agency
agence spatiale européenne

JUR/231/AMB/ab/2385

Paris, 17 April 1996

Mr. John D. Schumacher
Associate Administrator for
External Relations
IRD
NASA Headquarters
Washington, DC 20546-0001
U.S.A.

Subject : **NASA-ESA Memorandum of Understanding (MOU) for Ulysses**

Dear Mr. Schumacher,

In response to your letter of 11 April 1996, I am pleased to inform you that, the Council of the European Space Agency having approved the extension of the Ulysses mission in the light of continuing our fruitful cooperation, the NASA-ESA Memorandum of Understanding for Ulysses is extended.

This letter, along with the MOU signed in 1979, our letter of 31 March 1995 and your letter of 11 April 1996, constitute our agreement to extend the Ulysses mission.

Yours sincerely,

R. Bonnet
Director of the Scientific Programme

8-10 rue Mario-Nikis 75738 Paris Cedex 15 - ✆ (33.1) 53 69 76 54
Télécopieur (33.1) 53 69 75 60 - Télex ESA 202746 - Télégr. Spaceurop Paris

G

Letter from the European Space Agency to the Vice President of the United States, June 13, 1994

esa

european space agency
agence spatiale européenne

D.SCI/RMB/db/3948

Paris, 13 JUIN 1994

Jean-Marie Luton
Director General

The Honorable
Albert Gore, Jr.
Vice President of the
United States
Old Executive Office Building
Washington, DC 20501
USA

Dear Mr. Vice President,

I have recently received a number of disturbing reports that suggest that the continuation of the joint U.S./European CASSINI mission could be threatened by ongoing Congressional deliberations on NASA's FY95 Appropriations Bill.

I am aware that the House version of the Bill, as marked up by the House VA-HUD and Independent Agencies Subcommittee on June 9, retains the necessary funding for NASA's portion of the mission. However, I am also aware that the House Subcommittee's Senate counterpart is faced with a more stringent budget allocation. I am told that the Subcommittee Chair, Senator Mikulski, has indicated that without an increase in said allocation, termination of a major NASA programme would have to be contemplated, with specific reference being made to the CASSINI mission.

In the field of space science, CASSINI is the most significant planetary mission presently being undertaken by either the European Space Agency (ESA) or NASA, involving the exploration of Saturn, the most complex planet in the solar system and of its Moon, Titan. It is expected to provide at least a ten-fold increase in our knowledge of both bodies as compared to NASA's highly successful Voyager mission.

In making the commitment to participate with the U.S. in 1989, ESA oriented its overall space science programme in order to select this cooperative project, rather than opt for one of a number of purely European alternatives that were proposed at the same time. This decision was taken on the basis of scientific merit and in the belief that the cooperation would be of major benefit to both the U.S. and European scientific communities as well as the international science community in general. Over the past five years, while ESA's Long-Term Space Plan has been forced to undergo a series of significant revisions, driven primarily by our own budget limitations, the Member States have maintained a full commitment to the space science portion of the plan, of which CASSINI is an essential component.

To date, the Member State governments of ESA have committed around $300 Million to our portion of the mission (the Huygens Probe that will descend into the atmosphere of Saturn's Moon Titan, and several elements of the Saturn Orbiter Payload), of which two-thirds have already been spent, and have committed to a further expenditure of around $100 Million to see the mission through to completion. These figures do not include the approximately $100 Million contribution of Italy via a NASA/Italian Space Agency bilateral agreement.

The HUYGENS programme has been in the hardware phase for the past four years, with probe delivery to NASA due to take place in two years time. The hardware integration and testing phase started in early May this year.

The CASSINI mission has generated intense interest in Europe, both within the scientific and engineering community and from the public at large. Approximately 900 European scientists and engineers are working on the programme with more than 30 European institutes and universities involved in the preparation of CASSINI/HUYGENS science.

Europe therefore views any prospect of a unilateral withdrawal from the cooperation on the part of the United States as totally unacceptable. Such an action would call into question the reliability of the U.S. as a partner in any future major scientific and technological cooperation.

I urge the Administration to take all necessary steps to ensure that the U.S. commitment to this important cooperative programme is maintained so that we shall be able to look forward to many more years of fruitful cooperation in the field of space science.

Respectfully,

J.M. Luton

H

Acronyms and Abbreviations

ACS	Advanced Camera for Surveys (on HST)
AGHF	Advanced Gradient Heating Facility
AMPTE	Active Magnetospheric Particle Tracer Explorer
ANS	Astronomical Netherlands Satellite
AO	Announcement of Opportunity
APCF	Advanced Protein Crystallization Facility
APL	Applied Physics Laboratory (Johns Hopkins University)
APT	Automatic Picture Transmission
ARGOS	Advanced Research and Global Observations Satellite (France)
ASA	Austrian Space Agency
ASI	Agenzìa Spaziale Italiana [Italian Space Agency]
ASTP	Apollo-Soyuz Test Project
ATLAS	Atmospheric Laboratory for Applications and Science
AVHRR	Advanced Very High Resolution Radiometer
AVISO	Archiving, Validation and Interpretation of Satellite Oceanographic [Data Center]
AWG	Astronomy Working Group (ESA) Astrophysics Working Group (ESRO)
AXAF	Advanced X-Ray Astronomy Facility
BDPU	Bubble, Drop, and Particle Unit
BMFT	Bundesministerium für Forschung und Technologie (Germany)
BNSC	British National Space Centre
BOREAS	Boreal Ecosystem-Atmosphere Study (of Central Canada)
CAC	Cost at completion
CCE	Charge Composition Explorer (on AMPTE)
CDTI	Centro para el Desarrollo Tecnológico Industrial [Center for Industrial Technology Development] (Spain)
CEOS	Committee on Earth Observation Satellites
CERES	Clouds and Earth's Radiant Energy System
CERN	Centre d'Études et de Recherches Nucléaires (European Laboratory for Particle Physics)
CFZF	Commercial Float Zone Furnace

CGMS	Coordination Group for Meteorological Satellites
CISP	Committee on International Space Programs (U.S.)
CLAES	Cryogenic Limb Array Etalon Spectrometer
CNES	Centre National d'Études Spatiales (French Space Agency)
COMPLEX	Committee on Planetary and Lunar Exploration
COS	Cosmic Ray Satellite (Germany)
COS-B	Cosmic Ray Satellite B
COSPAR	Committee on Space Research
COSTAR	Corrective Optics Space Telescope Axial Replacement (HST)
CPCG	Commercial Protein Crystal Growth Facility
CPF	Critical Point Facility
CRAF	Comet Rendezvous Asteroid Flyby
CRISTA	Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere
CRRES	Combined Release and Radiation Effects Satellite
CSA	Canadian Space Agency
CSLM	Coarsening in Solid-Liquid Mixtures Facility
D/APP, D/SCI	Directorate of Application Programmes, Directorate of Scientific Programmes
DARA	Deutsche Agentur für Raumfahrt Angelegenheiten (German Space Agency)
DCE	Droplet Combustion Experiment
DISCO	Dual Spectral Irradiance and Solar Constant Orbiter
DLR-PT	Deutsches Zentrum für Luft- und Raumfahrt-Projektträger [German Center for Air and Spaceflight Projects]
DME	Direct Measurement Explorer
DOD	Department of Defense (U.S.)
DORIS	Détermination d'Orbite et Radiopositionnement Intégré par Satellite [Doppler Orbitography and Radiopositioning Integrated by Satellite]
DSN	Deep Space Network
DSRI	Danish Space Research Institute
ECF	European Coordinating Facility
EGS	EOS Ground System
ELDO	European Launcher Development Organization
ELV	Expendable Launch Vehicle
ENVISAT	Environmental Satellite
EOAC	Earth Observation Advisory Committee
EO-ICWG	Earth Observation International Coordination Working Group
EOIM	Evaluation of Oxygen Interaction with Materials
EOPP	Earth Observation Preparatory Programme
EOS	Earth Observing System
EOSDIS	Earth Observing System Data and Information System
EOSAT	Earth Observing Satellite Company
EPS	European Physical Society
EROS	Earth Resource Observation Satellite
ERS	European Remote Sensing (satellite)
ERTS	Earth Resources Technology Satellite (now Landsat)
ESA	European Space Agency
ESAC	Earth Science Advisory Committee (ESA)
ESE	Earth Science Enterprise
ESF	European Science Foundation
ESO	European Southern Observatory
ESOC	European Space Operations Center

ESPOIR	European Symposium on Opportunities and Instrumentation for Remote Sensing
ESRO	European Space Research Organization
ESSAAC	Earth System Science and Applications Advisory Committee
ESSC	European Space Science Committee
ESSP	Earth System Science Pathfinder
ESTEC	European Space Research and Technology Centre
EU	European Union
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EURECA	European Retrievable Carrier
EUTELSAT	European Telecommunications Satellite Organization
EUV	Extreme ultraviolet
EXOSAT	European Space Agency's X-Ray Observatory Satellite (formerly HELOS)
FAST	Fast Auroral Snapshot Explorer
FAUST	Far Ultraviolet Space Telescope
FFEU	Free Flow Electrophoresis Unit
FGS	Fine Guidance Sensors (on HST)
FIFE	First International Land Surface Climatology Project (ISLSCP) Field Experiment
FOC	Faint Object Camera (on HST)
FORBAIRT	Technical and economic development entity (Ireland)
FOS	Faint Object Spectrometer (on HST)
FUSE	Far Ultraviolet Spectroscopic Explorer
GAO	General Accounting Office (U.S.)
GARP	Global Atmospheric Research Program
GAS	Get Away Special
GEOS	Geostationary satellite
GHRS	Goddard High Resolution Spectrometer (on HST)
GMM	Generic Mars mission
GNP	Gross national product
GO	Guest observer
GOES	Geostationary Operational Environmental Satellite
GPPF	Gravitational Plant Physiology Facility
GPS	Global Positioning System
GRACE	Gravity Recovery and Climate Experiment
GRASP	Gamma-Ray Spectroscopy and Positioning (telescope)
GRGS	Group de Recherche de Géodésie Spatiale [Research Group for Space Geodesy]
GRIST	Grazing Incidence Solar Telescope
GRO	Gamma-Ray Observatory
GRS	German Research Satellite
GSFC	Goddard Space Flight Center
GSOC	Guide Star Occultation Prediction Utility
HAPEX	Hydrological and Atmospheric Pilot Experiment in the Sahel
HCMM	Heat Capacity Mapping Mission
HEAO	High Energy Astronomical Observatory
HEDS	Human Exploration and Development of Space Enterprise
HEOS	Highly Eccentric Orbit Satellite
HRI	High Resolution Imager (on ROSAT)
HST	Hubble Space Telescope
HUD	Department of Housing and Urban Development (U.S.)
HZE	High-Charge *Z* and High-Energy Particles
IACG	Inter-Agency Consultative Group (for Space Science)

IAS	Infrared Astronomical Satellite
IAU	International Astronomical Union
IBIS	Imager on Board the INTEGRAL Satellite
ICE	International Cometary Explorer
ICSU	International Council of Scientific Unions
IGBP	International Geosphere-Biosphere Program
ILSCP	International Land Surface Climatology Project
IML	International Microgravity Laboratory
IMP	Interplanetary Monitoring Platform
IMRC	International Mission Review Committee
IMS	International Magnetospheric Study
IMSCIE	International Magnetospheric Study Central Information Exchange
IMWG	International Mission Working Group
INTASAT	Instituto Nacional de Tecnica Aerospacial Satellite
INTEGRAL	International Gamma-Ray Astrophysics Laboratory
IPS	Instrument Pointing System
IRAS	Infrared Astronomical Satellite
IRM	Ion Release Module (on AMPTE)
ISAS	Institute for Space and Astronautical Science (Japan)
ISEE	International Sun-Earth Explorer
ISLSCP	International Satellite Land-Surface Climatology Project
ISO	Infrared Space Observatory
ISPM	International Solar Polar Mission (later renamed Ulysses)
ISS	International Space Station
ISTP	International Solar-Terrestrial Physics program
IUC	International Users Committee (for ROSAT)
IUE	International Ultraviolet Explorer
IUS	Interim Upper Stage
JEM-X	Joint European X-Ray Monitor (on INTEGRAL)
JERS	Japanese Earth Resources Satellite
JPL	Jet Propulsion Laboratory
JSWT	Joint Science Working Team
JWG	Joint Working Group
LAGEOS	Laser Geodynamics Satellite
LANS	Astronomical Netherlands Satellite
LDEF	Long Duration Exposure Facility
LEGOS	Laboratoire en Géophysique et Océanographie Spatiale
LMS	Life and Microgravity Spacelab
LMScAAC	Life and Microgravity Sciences and Applications Advisory Committee
LST	Large Space Telescope
MAHRSI	Middle Atmosphere High-Resolution Spectrograph Investigation
MAROTS	Maritime Communications Satellite Program
MAU	Million accounting units
MAUS	Materialwissenschaftliche Autonome Experimente unter Schwerelosigkeit
MEA	Materials Experiment Assembly
MEPHISTO	Matériel pour l'Étude des Phenomenes Interessant de la Solidification sur Terre et en Orbit
MESUR	Mars Environmental Survey
METEOSAT	European Geostationary Meteorological Satellite
METOP	Meteorological Operational Satellite
MFC	Microgravity Facility for Columbus

MGCO	Mars Geoscience and Climatology Orbiter
MIMR	Multifrequency Imaging Microwave Radiometer
MLS	Microwave Limb Sounder
MMA	Microgravity Measurement Assembly
MO&DA	Mission operations and data analysis (U.S.)
MOU	Memorandum of Understanding
MPE	Max-Planck-Institut für extraterrestrische Physik
MRLS	Microgravity research and life sciences
MSG	METEOSAT Second Generation
MSL	Microgravity Science Laboratory
MSS	Multispectral Scanner (on Landsat)
MTPE	Mission to Planet Earth (former name of Earth Science Enterprise)
NAE	Nuclear Astrophysics Explorer
NAS	National Academy of Sciences (U.S.)
NASA	National Aeronautics and Space Administration (U.S.)
NASDA	National Space Development Agency (Japan)
NGST	Next Generation Space Telescope
NICMOS	Near-Infrared Camera and Multi-Object Spectrometer (on HST)
NIMBUS	NASA environmental research satellite series
NOAA	National Oceanic and Atmospheric Administration (U.S.)
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NRC	National Research Council (U.S.)
NSC	Norwegian Space Centre
OAO	Orbiting Astronomical Observatory
OES	Office of Earth Science (formerly Office of Mission to Planet Earth)
OGO	Orbiting Geophysical Observatory
OMB	Office of Management and Budget (U.S.)
OMC	Optical Monitoring Camera (on INTEGRAL)
OOE	Out of ecliptic (mission)
OPEN	Origins of Plasmas in the Earth's Neighborhood
OPST	Outer Planets Study Team
ORFEUS	Orbiting and Retrievable Far and Extreme Ultraviolet Spectrometer
OSO	Orbiting Solar Observatory
OSSA	Office of Space Science and Applications (U.S.-NASA)
OSTA	Office of Space Technology and Applications (NASA)
OSTP	Office of Science and Technology Policy (U.S.)
PI	Principal investigator
PODAAC	Physical Oceanography Distributed Active Archive Center
POEM	Polar Orbit Earth Observation Mission
POGO	Polar Orbiting Geophysical Observatory
POPE	Polar Orbiting Platform Element
PPARC	Particle Physics and Astronomy Research Council (U.K.)
PRARE	Precise Range and Range-rate Equipment
PRODEX	Programme de Développement d'Expériences Scientifiques [Science Experiment Development Programme] (ESA)
PSG	Project Science Group
PSPC	Position Sensitive Proportional Counter (on ROSAT)
RAHF	Research Animal Holding Facility
ROSAT	Roentgen Satellite
RSDC	ROSAT Science Data Center

RTG	Radioisotope thermoelectric generator
SADM	Solar Array Drive Mechanism
SAF	Space Agency Forum
SAO	Smithsonian Astrophysical Observatory
SAR	Synthetic Aperture Radar
SARSAT	Search and Rescue Satellite
SDI	Strategic Defense Initiative
SERC	Science and Engineering Research Council (U.K.)
SIR	Shuttle Imaging Radar
SIRIO	Italian Satellite for Industrially Oriented Research
SIRTF	Space Infrared Telescope Facility
SLS	Spacelab Life Sciences
SME	Solar Mesospheric Explorer
SMM	Solar Maximum Mission
SNSB	Swedish National Space Board
SOHO	Solar and Heliospheric Observatory
SPAS	Shuttle Pallet Satellite (Germany)
SPC	Science Programme Committee (ESA)
SPOT	Système Pour l'Observation de la Terre
SRL	Space Radar Laboratory
SRON	Stichting Ruimteonderzoek Nederland [Space Research Organization Netherlands]
SSAC	Space Science Advisory Committee (ESA)
SSB	Space Studies Board (U.S.)
SSC	Swedish Space Corporation
SScAC	Space Science Advisory Committee (NASA)
SSE	Space Science Enterprise
SSEC	Solar System Exploration Committee of the NASA Advisory Council
SSO	Swiss Space Office
SST	Supersonic transport
SSTC	Services Federaux des Affairs Scientifiques, Techniques et Culturelles [Federal Service for Scientific, Technical, and Cultural Affairs] (Belgium)
SSWG	Solar System Working Group (ESA)
STEP	Satellite to Test the Equivalence Principle
STIC	Space Telescope Institute Council
STIS	Space Telescope Imaging Spectrograph
STJ	Superconducting Tunnel Junction
STS	Space Transportation System (U.S. Space Shuttle)
STScI	Space Telescope Science Institute
STSP	Solar Terrestrial Science Program
SURGE	Seasat Users Research Group of Europe
SWT	Science working team
TD	Thor Delta
TEKES	Technology Development Centre (Finland)
TEMPUS	Electromagnetic Containerless Processing Facility
TIROS	Television Infrared Observing Satellite
TM	Thematic Mapper
TOGA	Tropical Ocean Global Atmosphere Program
TOPEX	(Ocean) Topography Experiment
TPSG	Terrestrial Planets Study Group
TVD	Torque Velocity Dynamometer

UARS	Upper Atmosphere Research Satellite
UK	United Kingdom
UKDC	United Kingdom Data Centre (ROSAT)
UKGOC	United Kingdom Guest Observer Centre
UKS	United Kingdom Subsatellite (on AMPTE)
US-CREST	United States Center for Research and Education on Strategy and Technology
USML	U.S. Microgravity Laboratory
USMP	U.S. Microgravity Payload
UV	Ultraviolet
VA	Department of Veterans Affairs (U.S.)
VEGA	Venera (Venus)-Halley (former U.S.S.R.)
WCRP	World Climate Research Programme
WFC	Wide Field Camera
WFPC	Wide Field and Planetary Camera (on HST)
WOCE	World Ocean Circulation Experiment
WWW	World Weather Watch
XMM	X-Ray Multi-Mirror Mission
XRT	X-Ray Telescope (on ROSAT)
X-SAR	X-band Synthetic Aperture Radar
XUV	Extreme ultraviolet