Space Studies Board

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NATIONAL RESEARCH COUNCIL

Space Studies Board

Annual Report

1991

NATIONAL RESEARCH COUNCIL

National Academy Press
Washington, D.C. 1994

The Space Studies Board is a unit of the National Research Council, which serves as an independent advisor to the federal government on scientific and technical questions of national importance. The Research Council, jointly administered by the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine, brings the resources of the entire scientific and technical community to bear through its volunteer advisory committees.

Support for the work of the Space Studies Board and its committees and task groups was provided by National Aeronautics and Space Administration contracts NASW-4201 and NASW-4627 and National Oceanic and Atmospheric Administration contract 50-DGNE-1-00138.

From the Chair

Since its founding as the Space Science Board in 1958, the Space Studies Board has provided independent external scientific and technical advice on the nation's civil space program. This 1991 Annual Report of the SSB and its committees represents the first of its kind. The report contains a summary of the Board's meetings, complete texts of letter reports, and executive summaries of full reports issued during the year. It is intended to serve as a ready reference to Board activities and advisory reports in 1991.

The year 1991 began in the context of the recommendations for the civil space program that were contained in the "Report of the Advisory Committee on the Future of the U.S. Space Program." This committee had been convened by the National Space Council and issued its report in December 1990. I served as one of twelve members. The committee recommended that space science should be the highest priority, the "fulcrum," of the space program. Two major initiatives, Mission to Planet Earth and Mission from Planet Earth, were identified, with Mission from Planet Earth being recommended on a go-as-you-pay basis. Basic infrastructure elements that were the subject of recommendations were space technology and launch systems. Management advice for the space program was also presented.

In early 1991 NASA completed another redesign of Space Station Freedom. The Board and its Committees on Space Biology and Medicine and on Microgravity Research examined the redesigned station and concluded, in a letter report, that "[n]either the quantity nor the quality of research that can be conducted on the proposed station merits the projected investment." Explaining, discussing, and testifying on this Board report occupied a significant amount of time and attention of the Chair and the staff as the 1992 budgetary process worked its way through the Congress.

It became very clear from the space station discussions in 1991 that, even though this program eventually received full funding from the Congress after first being defeated in its House Appropriations Subcommittee, controversy over the nation's interest in the endeavor was not ended. It will be interesting to follow its saga into the future and to watch the extent to which technical advisory reports such as those of the Board or of the National Space Council's Advisory Committee on this major program are utilized by lawmakers.

The year 1991 occupied an interval of some twelve to twenty-four months after the fall of the Berlin Wall, with all that that event portended for the future of the peoples of Eastern Europe. I have begun to sense a questioning of some aspects of the space program, particularly those most closely associated with issues of national pre-eminence. At the same time, the political changes suggest a brighter future for collaborative enterprises in space with former adversaries.

I hope that this summary report of the 1991 activities of the Space Studies Board will indeed be helpful to future researchers and policymakers. I also hope that this report will be but the first in a continuing series that chronicles in a useful way the advisory actions of this Board of the National Research Council.

Louis J. Lanzerotti
Chair
Space Studies Board

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1
History and Charter of the Board

ORIGIN OF THE SPACE SCIENCE BOARD

The National Academy of Sciences was chartered by the Congress, under the leadership of President Abraham Lincoln, to provide scientific and technical advice to the government of the United States. Over the years, the advisory program of the institution expanded, leading in time to the establishment of the National Academy of Engineering and the Institute of Medicine, and of the National Research Council, today's operational arm of the Academies of Sciences and Engineering.

After the launch of Sputnik in 1957, the pace and scope of U.S. space activity were dramatically increased. Congress created the National Aeronautics and Space Administration (NASA) to conduct the nation's ambitious space agenda, and the National Academy of Sciences created the Space Science Board. The original charter of the Board was established in June 1958, three months before final legislation creating NASA was enacted. The Space Science Board has provided external and independent scientific and programmatic advice to NASA on a continuous basis from its inception until the present.

REORGANIZATION OF THE BOARD— CREATION OF THE SPACE STUDIES BOARD

In 1988, the Space Science Board undertook a series of retreats to review its structure and charter. These retreats were motivated by the Board's desire to more closely align the structure of the Board and its activities with evolving government advisory needs and by its assumption of a major portion of the responsibilities of the disestablished Space Applications Board. As a result of these retreats, a number of new task groups and committees were formed, and several committees were disbanded and their portfolios distributed to other committees. The Committee on Data Management and Computation and its activities were terminated. The Committee on Planetary Biology and Chemical Evolution was also dismantled, but its responsibilities were distributed to other discipline committees and task groups. The charters of the remaining committees were revised, and an Executive Council of the Board was created to assist the chair of the Board in managing Board activities.

Recognizing that civilian space research now involves federal agencies other than NASA (for example, the National Oceanic and Atmospheric Administration (NOAA), the Departments of Energy and Defense, and the National Science Foundation (NSF)), it was decided to place an increased emphasis on broadening the Board's advisory outreach. In addition, the Board considered the possibility that an enhanced international program would necessitate more formal relationships with the Department of State.

CHARTER OF THE BOARD

The basic elements of the charter of the Board remain those defined by National Academy of Sciences President Detlev Bronk on June 26, 1958:

> We have talked of the main task of the Board in three parts—the immediate program, the long-range program, and the international aspects of both. In all three we shall look to the Board to be the focus of the interests and responsibilities of the Academy-Research Council in space science; to establish necessary relationships with civilian science and with governmental science activities, particularly the proposed new space agency, the National Science Foundation, and the Advanced Research Projects Agency; to represent the Academy-Research Council complex in our international relations in this field on behalf of American science and scientists; to seek ways to stimulate needed research; to promote necessary coordination of scientific effort; and to provide such advice and recommendations to appropriate individuals and agencies with regard to space science as may in the Board's judgment be desirable.
>
> As we have already agreed, the Board is intended to be an advisory, consultative, correlating, evaluating body and not an operating agency in the field of space science. It should avoid responsibility as a Board for the conduct of any programs of space research and for the formulation of budgets relative thereto. Advice to agencies properly responsible for these matters, on the other hand, would be within its purview to provide.

Thus, the Board exists to provide advice to the federal government on space research and to assist in coordination of the nation's undertakings in these areas. Since its reconstitution in 1988 and 1989, the Board has also assumed similar responsibilities with respect to space applications. More recently, the Board has begun to address scientific aspects of a program of human exploration of the Moon and Mars.

In general, the Board develops and documents its views by means of appointed discipline committees or interdisciplinary task groups that conduct studies and submit their findings for Board and National Research Council approval and dissemination. On occasion, however, the Board itself considers major issues in its own plenary sessions and prepares and releases its own statements. These various advisory products may be prepared and released either in response to a government request or on the Board's own initiative. In addition, the Board comments, based on its publicly established opinions, in testimony to Congress.

The Board's overall charter is expressed in several subordinate components: discipline oversight, interdisciplinary studies, international activities, and advisory outreach.

OVERSIGHT OF SPACE RESEARCH DISCIPLINES

The Board has responsibility for strategic planning and oversight in the numerous subdisciplines of space research. This responsibility is discharged through a discipline committee structure and includes preparation of strategic research plans as well as assessment of progress and prioritization of objectives in these disciplines. The standard vehicle for providing long-term research guidance is the research strategy report, which has been used successfully by the Board over many years. In addition, committees may prepare formal assessment reports that examine progress in a discipline in comparison with published Board advice. Committee reports undergo Board and National Research Council review and approval prior to publication. Formally, all Board committee reports are issued as reports of the Board.

Individual discipline committees may be called on by the Board, from time to time, to prepare specialized material for use by either the Board or its interdisciplinary committees or task groups.

INTERDISCIPLINARY STUDIES

While the emphasis over the years has been on discipline planning and evaluation, the reorganization of the Board recognized a need for crosscutting technical and policy studies in several important areas. To accomplish these objectives, the Board creates executive committees of the Board and ad hoc task groups. Executive committees, constituted exclusively of Board members, are formed for short-period study activities or to serve as initial planning bodies for topics that require subsequent formation of a regular committee or task group. Task groups resemble discipline committees in structure and operation, except that they have finite terms of operation, typically two to three years, and specifically limited tasks.

INTERNATIONAL REPRESENTATION

The Board continues to serve as the U.S. National Committee for the International Council of Scientific Unions (ICSU) Committee on Space Research (COSPAR). The U.S. vice president of COSPAR serves as a member of the Board, and a member of the Board's staff serves as executive secretary for this office. In this capacity, the Board participates in a broad variety of COSPAR panels and committees.

As the economic and political integration of Europe progresses, so also does the integration of Europe's space activities. The Board has successfully collaborated with the European space research community on a number of ad hoc joint studies in the past and seeks in a measured way to nurture a joint advisory relationship with this community.

ADVISORY OUTREACH

The Space Science Board was conceived to provide space research guidance across the federal government. Over the years, the Board's agenda and funding have tended to focus on NASA's space science program. Since the Board's reorganization, however, several influences have acted to expand the breadth of the Board's purview, both within NASA and outside it.

First, the incorporation of scientific objectives into manned flight programs such as the shuttle and space station programs, and possibly the Space Exploration Initiative (SEI), necessitates additional interfaces with responsible offices in NASA.

Second, the assumption of the space applications responsibilities from the dissolved Space Applications Board has implied a broadening of the sponsorship base, for example to NOAA, with its responsibilities for operational weather satellites. The Department of Commerce also has public responsibility for oversight of the privatized operator of the national civilian land sensing system.

Third, the maturation of some of the physical sciences may lead to progressive integration of space and nonspace elements, suggesting a more highly integrated advisory structure. One example is the solar-terrestrial community, where the Board's Committee on Solar and Space Physics has operated for several years in a "federated" structure with the ground-based NRC Committee on Solar-Terrestrial Research. Another example is astronomy; the recently completed report of the Astronomy and Astrophysics Survey Committee promotes a much closer relationship between space astronomy and ground-based astronomy, the latter primarily supported by the National Science Foundation.

Finally, it is becoming more and more apparent that new participants will be involved in space exploration, particularly the Departments of Energy and Defense and the Strategic Defense Initiative Office (SDIO). This is motivated in part by technology programs of mutual interest with NASA, for example, nuclear space propulsion and power systems with the former, and joint development of heavy launch systems with the latter.

As a response to these developments, the Board must reach out to nonresearch NASA offices and to other federal agencies, seeking to establish both informal and advisory and corresponding sponsorship relationships as appropriate.

2
Activities and Membership

The Space Studies Board greeted 1991 promptly with its 101st meeting, held on January 3-4 in the Board Room of the National Academy of Sciences in Washington, D.C. The *Report of the Advisory Committee on the Future of the U.S. Space Program* had just been released, and the chair of the committee, Mr. Norman Augustine, visited with the Board to discuss its findings. Members subsequently had the opportunity to discuss these findings with Dr. Berrien Moore, chair of the Space Science and Applications Advisory Committee (SSAAC), and Dr. Lennard Fisk, Associate Administrator for Space Science and Applications, who also gave a briefing on the status of NASA space research programs. The Board closed the meeting with internal discussions about its international program, operating plan, and activities of several of its committees.

A second meeting of the Board (the 102nd) was held at the Jet Propulsion Laboratory in Pasadena, Calif., on February 27 to March 1. Office of Space Science and Applications (OSSA) head Dr. Lennard Fisk gave a detailed presentation of the FY92 budget for space science. The 1990/1991 Space Station Freedom redesign activity was in its final stages, and much of the remainder of the meeting agenda focused on discussing this program. The Board was briefed by NASA officials Mr. William Raney and Dr. John-David Bartoe on the unreleased results of the redesign. After follow-up discussion, the Board broke up into working groups to draft an assessment of the redesign as presented. The Board also approved the last of its 1991 discipline assessment report series (on Earth studies), as well as the final sections of its Earth Observing System (EOS) assessment report. A major topic addressed at the meeting was a proposed study on NASA's Research and Analysis program and research productivity.

Continuing with a vigorous meeting schedule, the Board met for its 103rd gathering, the third in 1991, in Washington on May 22-23. This meeting was devoted principally to committee business but included a teleconversation with Dr. John Bahcall on his committee's recent report, *The Decade of Discovery in Astronomy and Astrophysics*, a science presentation by Dr. Joseph Boyce on Magellan results, and a description by Gen. Sam Armstrong of the work and findings of the Synthesis Group on a human exploration program for the nation. The Board discussed its international program and considered a restructured version of its EOS assessment report, the status of its human exploration committee's studies, the conclusions and recommendations of its first and nearly complete microgravity science report, and plans of its planetary protection task group and of its joint committee on technology. Members also surveyed developments in the space station program since the February meeting and release of the Board's assessment report on the redesign.

On May 28 and 29, several members of the Executive Council of the Board, augmented by Board members Drs. Noel Hinners and William Merrell, attended a meeting of the European Space Science Committee (ESSC) in Copenhagen, Denmark. The objective of the meeting was to ascertain if it would be feasible and desirable to formalize a process, under development for some time, for collaborative work between the two groups. Extended discussion of the environments and advisory postures of the two groups led to a shared conclusion that this step would be difficult at present, but that a strengthened liaison relationship would be valuable and could lead to closer and more routine collaboration in the future.

During this period in early and mid-year, there was a dramatic sequence of developments related to the space station, including endorsement by congressional authorizing committees, legislation directed at identifying alternative and/or complementary station concepts, deletion of station funding by the Committee on Appropriations, and restoration of funding on the floor of the House. On the science side, both the Gamma Ray Observatory and Ulysses successfully gathered scientific data. Magellan successfully completed its first "year" of mapping operations at Venus, revealing a planetary surface of bewildering complexity and enormous scientific interest, while Galileo developed unexpected high gain antenna deployment problems.

Even though the full Board did not meet during the third quarter, it was a busy summer. In addition to attending their individual committee meetings, Board committee chairs gathered on several occasions for long-term planning purposes. The Board also released the last of its four discipline assessment reports, *Assessment of Satellite Earth Observation Programs—1991*, as well as a letter report on the EOS program specifically, and a letter report on the Landsat program.

On July 12, Chair Louis Lanzerotti convened a meeting of all Board committee and task group chairs to discuss future plans and participation in OSSA's strategic planning activity scheduled at Woods Hole later that month. With three years having passed since the Board's reorganization, it was becoming apparent that an update of the Board Operating Plan and individual committee plans was needed. The July 12 gathering considered and updated activity plans for the committees and task groups and established guidelines for Board members' participation at the OSSA Woods Hole meeting.

NASA's OSSA conducted its major strategic planning review at Woods Hole during the last week of July. At the invitation of Dr. Berrien Moore, chair of SSAAC, and of Mr. Joseph Alexander, OSSA assistant associate administrator, the committee chairs attended the first two days of the Woods Hole meeting to summarize committee assessments comparing discipline accomplishments to Board recommendations. While the chairs did not take part in programmatic prioritizations or mission ranking at the review, they were available as information resources to NASA division delegations. An important Board input to this process was its set of four assessment reports covering the disciplines of space biology and medicine, solar and space physics, planetary and lunar exploration, and earth studies from space.

On September 26, the Board was privileged to host a joint meeting of committee chairs, OSSA division managers, and representatives from NASA's Office of Aeronautics and Exploration Technology (OAET) and from the National Oceanic and Atmospheric Administration (NOAA) for the purpose of getting feedback on the usefulness of past Board advice, and on Board plans for the future. Planned future advisory undertakings were presented for validation against expected needs, and much useful program technical and budget information was exchanged. Board sponsors expressed satisfaction with the four assessment reports and a strong interest in prioritized, survey/strategy reports in a number of specific areas. Based on the results of this successful meeting, it was decided that the 1992 Board Operating Plan draft would be revised for submission to the Board at its next meeting on November 20-22 in Irvine, Calif.

On the international front, a small delegation from the Board and staff attended a second meeting of the ESSC in Paris in September. The visit was intended to continue liaison with this European advisory body, with a view to identifying joint study topics and possibly developing a more formal relationship in the future. Board member William Merrell represented Chair Louis Lanzerotti, who was unable to attend because of a conflict with the reconvening of the Augustine Committee. A substantial amount of time was devoted by ESSC members to discussing guidance for the November European Space Agency (ESA) ministerial meeting. The similarity of the major issues in the U.S. and European space communities, including how to deal with budget pressures and the tension between manned and unmanned projects, was striking. Board representatives described recent Board activities and preliminary results of the OSSA strategic planning process and heard presentations on initial results of the successful ERS-1 mission and plans for other ESA missions. Candidate topics for future joint advisory study were also discussed.

The Board met for its final meeting of 1991 (its 104th) on November 20-22 at the Beckman Center in Irvine. A broad range of topics was discussed. The Board heard a series of science briefings on topics in infrared astronomy, including the Infrared Astronomy Satellite (IRAS) and Caltech's Infrared Processing and Analysis Center (IPAC), and the proposed Space Infrared Telescope Facility (SIRTF) and airborne Stratospheric Observatory for Infrared Astronomy (SOFIA). Mr. Joseph Alexander, assistant associate administrator of OSSA, briefed the Board on the process and results of the strategic planning workshop held at Woods Hole in July 1991 and on the impacts of the FY92 appropriation passed by Congress. Various committee status reports were presented, and the first formal report of the Board's human exploration committee was approved for submission to NRC review. This first report deals with

research that remains to be done before the nation can confidently undertake a program of long-duration human spaceflight. COSPAR charter issues and opportunities for collaborative international studies with the ESSC were also discussed.

As 1991 drew to a close, the Board, committees, and staff could look back on a year of hard work and accomplishment. Four discipline assessment reports were published and distributed. The space station, the Earth Observing System (EOS) program, and Landsat were critically examined. Several important planning meetings were held, including one attended by NASA/OSSA division managers, as well as representatives of NASA/OAST and NOAA. The Board's operating plan was updated to acknowledge progress and changes since the reorganization of the Board in 1988—this in addition to ongoing work of the committees and task groups.

SPACE STUDIES BOARD

Meetings

January 3-4	National Academy of Sciences, Washington, D.C.
February 27-March 1	Jet Propulsion Laboratory, Pasadena, California
May 22-23	National Academy of Sciences, Washington, D.C.
November 20-22	Beckman Center, Irvine, California

Members

Louis J. Lanzerotti, *Chair*, AT&T Bell Laboratories
Philip Abelson,* American Association for the Advancement of Science
Joseph A. Burns, Cornell University
John R. Carruthers,* INTEL
Andrea K. Dupree, Harvard-Smithsonian Institution
John A. Dutton, Pennsylvania State University
Larry Esposito, University of Colorado
James P. Ferris, Rensselaer Polytechnic Institute
Herbert Friedman, Naval Research Laboratory
Richard L. Garwin, IBM Corporation
Riccardo Giacconi, Space Telescope Science Institute
Noel W. Hinners, Martin Marietta Civil Space & Communications Company
James R. Houck, Cornell University
David A. Landgrebe, Purdue University
Robert A. Laudise, AT&T Bell Laboratories
Elliott C. Levinthal,* Stanford University
Richard Lindzen, Massachusetts Institute of Technology
John McElroy, University of Texas at Austin
William J. Merrell, Jr., Texas A&M University at Galveston
Richard K. Moore, University of Kansas
Robert H. Moser, The NutraSweet Company
Norman F. Ness, University of Delaware
Marcia Neugebauer, Jet Propulsion Laboratory
Sally K. Ride,* University of California at San Diego
Robert F. Sekerka,* Carnegie Mellon University
Mark Settle, ARCO Oil and Gas Company
William Sirignano, University of California at Irvine
L. Dennis Smith,* University of California at Irvine
Byron D. Tapley,* University of Texas at Austin
Fred Turek, Northwestern University
Arthur B.C. Walker, Jr., Stanford University

Marc S. Allen, Director
Richard C. Hart, Deputy Director
Betty C. Guyot, Administrative Officer

*Term expired during 1991.

EXECUTIVE COUNCIL OF THE BOARD

Meetings

April 18	National Academy of Sciences, Washington, D.C.
May 28-29	Ministry of Education and Research, Copenhagen, Denmark

Members

Louis J. Lanzerotti, *Chair*, AT&T Bell Laboratories
Joseph Burns, Cornell University
James P. Ferris, Rensselaer Polytechnic Institute
Riccardo Giacconi, Space Telescope Science Institute
Norman F. Ness, University of Delaware
Mark Settle, ARCO Oil and Gas Company

COMMITTEE ON EARTH STUDIES

Meetings

February 7-8	Beckman Center, Irvine, California
May 6-7	Green Building, Washington, D.C.
November 18-19	Beckman Center, Irvine, California

Members

Byron D. Tapley, *Chair*, University of Texas at Austin
John R. Apel,* Applied Physics Laboratory
William P. Bishop,* Desert Research Institute
Kevin C. Burke,* Lunar and Planetary Institute
Janet W. Campbell, Bigelow Laboratories
Charles Elachi, Jet Propulsion Laboratory
William J. Emery, University of Colorado
Diana W. Freckman, University of California at Riverside
Richard E. Hallgren, American Meteorological Society
Kenneth C. Jezek, Ohio State University
Edward T. Kanemasu, University of Georgia
Victor Klemas, University of Delaware
Conway B. Leovy, University of Washington
John S. MacDonald, MacDonald-Dettwiler Associates
Alfredo E. Prelat, Texaco Corporation
John M. Wahr,* University of Colorado

Paul F. Uhlir, Executive Secretary
David H. Smith, Executive Secretary

*Term expired during 1991.

COMMITTEE ON HUMAN EXPLORATION

Meetings

February 26	Pasadena Hilton, Pasadena, California
August 5-9	Beckman Center, Irvine, California

Members

Noel W. Hinners, *Chair*, Martin Marietta Corporation
George Nelson Driver, University of Washington

Richard Garwin, IBM Corporation
Louis J. Lanzerotti, AT&T Bell Laboratories
Elliott C. Levinthal, Stanford University
William J. Merrell, Jr., Texas A&M University
Robert H. Moser, University of New Mexico
Sally K. Ride,* Stanford University

Marc S. Allen, Executive Secretary
David H. Smith, Executive Secretary

*Term expired during 1991.

COMMITTEE ON MICROGRAVITY RESEARCH

Meetings

January 10-11	Green Building, Washington, D.C.
April 29-30	Green Building, Washington, D.C.
November 18-19	Beckman Center, Irvine, California

Members

Robert F. Sekerka,* *Chair*, Carnegie Mellon University
Robert A. Brown, Massachusetts Institute of Technology
Martin E. Glicksman, Rensselaer Polytechnic Institute
Franklin D. Lemkey, United Technologies Research Center
Ronald E. Loehman, SNL
Simon Ostrach, Case Western Reserve University
Morton B. Panish, AT&T Bell Laboratories
John D. Reppy, Cornell University
William A. Sirignano, University of California at Irvine
Thomas A. Steitz, Yale University
Warren C. Strahle, Georgia Institute of Technology
Julia Weertman, Northwestern University

Joyce M. Purcell, Executive Secretary

*Term expired during 1991.

COMMITTEE ON PLANETARY AND LUNAR RESEARCH

Meetings

February 13-15	National Academy of Sciences, Washington, D.C.
July 15-19	Jonsson Center, Woods Hole, Massachusetts
October 28-29	Green Building, Washington, D.C.

Members

Larry W. Esposito, *Chair*, University of Colorado
Alan P. Boss, Carnegie Institution of Washington
Anita L. Cochran, University of Texas at Austin
Peter J. Gierasch, Cornell University
William S. Kurth, University of Iowa
Lucy-Ann McFadden, University of California at San Diego
Christopher P. McKay, NASA Ames Research Center
Duane O. Muhleman, California Institute of Technology
Norman R. Pace, Indiana University
Graham Ryder, Lunar and Planetary Institute

Paul D. Spudis, Lunar and Planetary Institute
Peter H. Stone, Massachusetts Institute of Technology
Richard W. Zurek, California Institute of Technology

Paul F. Uhlir, Executive Secretary
David H. Smith, Executive Secretary

COMMITTEE ON SPACE BIOLOGY AND MEDICINE

Meetings

February 7-8	Beckman Center, Irvine, California
May 13-15	Green Building, Washington, D.C.
October 17-18	Green Building, Washington, D.C.

Members

L. Dennis Smith,* *Chair*, University of California at Irvine
Robert M. Berne, University of Virginia at Charlottesville
Peter B. Dews, Harvard Medical School
R.J. Michael Fry, Oak Ridge National Laboratory
Frances Gaffney, University of Texas at Dallas
Edward J. Goetzel, University of California Medical School at San Francisco
Robert L. Helmreich, University of Texas at Austin
James Lackner, Brandeis University
Barry Wayne Peterson,* Northwestern University
Clinton T. Rubin, State University of New York at Stony Brook
Allan Schiller, Mt. Sinai Medical Center
Tom K. Scott, University of North Carolina at Chapel Hill
Warren Sinclair, National Council on Radiation Protection and Measurements
William Thompson, North Carolina State University
Fred W. Turek, Northwestern University
Fred Wilt, University of California at Berkeley

Joyce M. Purcell, Executive Secretary

*Term expired during 1991.

COMMITTEE ON SOLAR AND SPACE PHYSICS

Meetings

April 4-6	Green Building, Washington, D.C.
June 26-28	Green Building, Washington, D.C.
October 28-30	Green Building, Washington, D.C.

Members

Marcia M. Neugebauer, *Chair*, Jet Propulsion Laboratory
Thomas E. Cravens, University of Kansas
Martin A. Lee,* University of New Hampshire
Jonathan F. Ormes, Goddard Space Flight Center
George K. Parks, University of Washington
Douglas M. Rabin, National Optical Astronomy Observatory
David M. Rust, Johns Hopkins University
Raymond J. Walker, University of California at Los Angeles
Yuk L. Yung, California Institute of Technology
Ronald Zwickl, National Oceanic and Atmospheric Administration

Richard C. Hart, Executive Secretary

*Term expired during 1991.

JOINT COMMITTEE ON TECHNOLOGY FOR SPACE SCIENCE AND APPLICATIONS

Meeting

December 3 Green Building, Washington, D.C.

Members

David A. Landgrebe, *Chair*, Purdue University

Richard C. Hart, Executive Secretary

TASK GROUP ON PLANETARY PROTECTION

Meetings

May 21	Green Building, Washington, D.C.
November 13-14	Green Building, Washington, D.C.
September 9-13	Beckman Center, Irvine, California

Members

Kenneth H. Nealson, *Chair*, University of Wisconsin, Milwaukee
John A. Baross, University of Washington
Michael H. Carr, U.S. Geological Survey
Robert Pepin, University of Minnesota
Thomas M. Schmidt, Miami University
Jodi Shann, University of Cincinnati
J. Robie Vestal, University of Cincinnati
David C. White, Oak Ridge National Laboratory
Richard S. Young, consultant, Kennedy Space Center

Joyce M. Purcell, Executive Secretary

TASK GROUP ON PRIORITIES IN SPACE RESEARCH

Meetings

May 9-10	Green Building, Washington, D.C.
July 15-16	Green Building, Washington, D.C.
September 30-October 1	Green Building, Washington, D.C.

Members

John A. Dutton, *Chair*, Pennsylvania State University
Philip Abelson, American Association for the Advancement of Science
Steven V.W. Beckwith,* Cornell University
William P. Bishop, Desert Research Institute
Lawson Crowe, University of Colorado
Peter B. Dews, Harvard Medical School
Angelo Guastaferro, Lockheed Missiles and Space Company, Inc.
Molly K. Macauley, Resources for the Future
Buddy MacKay, Lt. Governor of Florida
Thomas A. Potemra, Johns Hopkins University
Arthur B.C. Walker, Jr., Stanford University

Joyce M. Purcell, Executive Secretary

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*Term expired during 1991.

3
Summaries of Reports

3.1 Assessment of Programs in Solar and Space Physics—1991

A Report of the Committee on Solar and Space Physics

INTRODUCTION

The Committee on Solar and Space Physics (CSSP) and the Committee on Solar Terrestrial Research (CSTR) are both responsible for providing scientific advice to U.S. government agencies in the overlapping fields of solar physics, space physics, and solar-terrestrial relationships. The CSSP is a subcommittee of and reports to the Space Studies Board (SSB); the CSTR has a similar relationship to the Board on Atmospheric Sciences and Climate (BASC). CSSP and CSTR now function as a single, federated committee reporting to both the SSB and BASC. This assessment report has been written in response to a request by the SSB for an assessment of the way in which prior recommendations of the National Research Council (NRC) are being implemented by the appropriate federal agencies (See Appendix A). The federated committee has expanded the scope of the study beyond that requested by the SSB to include an assessment of responses to NRC reports in solar-terrestrial research that are beyond the space-oriented scope of the SSB. This report was reviewed and approved by the SSB.

STATUS OF DISCIPLINE

The scientific purview of the CSSP and CSTR covers the disciplines of solar physics, heliospheric physics, cosmic ray physics, magnetospheric physics, middle- and upper-atmosphere physics, solar-terrestrial coupling, and comparative planetary studies. The assessment has two major sections: discipline-specific issues and common issues.

Discipline-Specific Issues

Solar Physics

Good progress has been made in studies of solar irradiance variations, high-energy emissions, and solar magnetism, resulting in part from the Solar Maximum Mission (SMM) and the development of ground-based Stokes polarimeters. Fundamental studies of helioseismology and solar neutrinos are slowly progressing. The principal problem areas are the lack of prospects for space observations of the highest-energy solar phenomena during both the current and the next solar maximum, multiyear gaps in solar irradiance measurements, lack of a

funded plan for U.S. participation in the Large Earth-Based Solar Telescope (LEST), and most critically, the extraordinarily long delay in achieving a new start for the Orbiting Solar Laboratory (OSL). Because of the breadth and importance of its scientific goals, OSL remains the top-priority candidate for a new mission start.

Heliospheric Physics

Extremely valuable data on the properties of the outer heliosphere continue to be received from the Pioneer and Voyager spacecraft. With the successful launch of Ulysses, the first in situ measurements of the three-dimensional structure of the heliosphere will be obtained in 1993-1995. Both Ulysses and Wind (to be launched in 1993) are expected to allow great advances in our knowledge of the abundance and charge state of solar wind ions. Problem areas are the lack of advanced development of technology required for future missions and the decline in support for ground-based radio observations of the solar corona and solar wind.

Cosmic Ray Physics

Data returned by the Voyager and Pioneer spacecraft, launched in the 1970s, gave valuable new insights into the modulation of galactic cosmic rays, the nature of anomalous cosmic rays, and the variable abundances of solar energetic particles. Although several other missions and experiments responsive to NRC recommendations were started, many of them were subsequently canceled or postponed indefinitely; others have been stretched out over more than a decade. The augmentation of the Explorer Program has led to the selection of two new cosmic ray missions—the Solar, Anomalous, and Magnetospheric Particle Explorer (SAMPEX) and the Advanced Composition Explorer (ACE).

Magnetospheric Physics

During the 1980s, a number of advances occurred that increased our understanding of magnetospheric physics, including definitive observations that the ionosphere is a major source of magnetospheric particles, initial measurements of the composition and charge state of the ring current, the discovery of plasmoids traveling at high velocity away from the Earth, and the development of new models of the Earth's magnetopause, bow shock, and foreshock regions. The key magnetospheric project, the International Solar-Terrestrial Physics (ISTP) program, has been subject to delays and descoping actions. Deletion of the Equator spacecraft eliminated crucial measurements of the equatorial magnetosphere. NASA is currently trying to develop other ways to obtain those key measurements. The several ISTP elements may, however, be spread out in time to the extent that there will be little of the simultaneity of measurements so vital to accomplishing the ISTP objectives. Although the mission of the recently launched Combined Release and Radiation Effects Satellite (CRRES) is to perform some active magnetospheric experiments, much of the active experiment program has been lost as a major element of magnetospheric research because of budget cuts and delays.

Middle- and Upper-Atmosphere Physics

There has been much progress in implementing NRC recommendations in this discipline; the Middle Atmosphere Program (MAP), the Coupling, Energetics, and Dynamics of Atmospheric Regions (CEDAR) program, and a series of satellite observations gave a major boost to studies of chemical, dynamical, radiation, and coupling processes. Recent studies of the polar ozone depletion are especially noteworthy, but the combination of long delays, such as in Upper Atmosphere Research Satellite (UARS); the lack of a vigorous research program on the effects of solar activity on the middle atmosphere; and some gaps in addressing the global electric circuit problem, has reduced expected progress in some important areas.

Solar-Terrestrial Coupling

Progress in solar-terrestrial coupling has been closely related to results in the areas of magnetospheric and atmospheric physics. Those results, mostly tied to programs defined in the 1970s and conducted in the 1980s, have improved our understanding of the solar wind-magnetosphere-ionosphere interactions and resulting dynam-

ics. The programmatic delays from planning to implementation have meant that most of the solar-terrestrial recommendations made through the 1980s will not be acted on until the 1990s. Illustrative of programs that are expected to provide major advances in this area are the ISTP, CEDAR, and Geospace Environmental Modeling (GEM) programs.

Comparative Planetary Studies

Observations of planetary magnetospheres and atmospheres continue to be an important element of solar system exploration. The Voyager flybys of Uranus and Neptune added two new planets to the list of objects available for comparative studies of planetary magnetospheres and magnetosphere-ionosphere-atmosphere interactions. But again, major delays (e.g., in the Galileo and CRAF/Cassini missions) and the absence of a U.S. mission to comet Halley have significantly slowed the implementation of recommendations in this area.

Common Issues

Program Management

The recommended establishment of a separate Space Physics Division within NASA's Office of Space Science and Applications (OSSA) has been successfully implemented. The recommended reorganization of the solar physics program within NSF is still under consideration. The recommended interagency coordination council for solar-terrestrial research was formed, but has not been active since 1987. International coordination has been excellent.

Data Archiving and Access

The recommended solar-terrestrial Central Data Catalog and Data Access Network have not been implemented. Although there have been some initial developments in this area, progress has been painfully slow. A great deal needs to be done before the NRC recommendations are met.

Explorer Program

The recommendations of an augmentation of the Explorer program and the institution of a two-stage selection process have both been implemented, as has the recommendation for a return to a concept of small, simple missions. The recommended level of an average of one Explorer per year for solar and space physics has not been reached, however, because cost overruns in the current Explorer program continue to cause delays.

Coordinated Programs and Synoptic Observations

Several initiatives have responded to recommendations for coordinated programs. Examples include ISTP and CEDAR. To date, there is no national program or policy supporting recommendations for synoptic observations of the fundamental parameters of the solar-terrestrial system. One exception was NASA's successful effort to increase the data return from the IMP-8 spacecraft.

Research and Analysis

Even though support and augmentation of the research base have been recommended by virtually every report, the base appears to have eroded. In addition to this major concern, agency responses to other specific recommendations in this area include the following:

1. *Theory and modeling.* NASA's Space Physics Theory Program (previously called the Solar-Terrestrial Theory Program) has been very successful, but there is concern about the steady erosion of average grant sizes in real-year dollars.

2. *Supercomputing*. Recommendations for access to supercomputers for solar-terrestrial research have largely been met. The limiting factor for many scientists is now the lack of the small, inexpensive workstations required to communicate with the supercomputers and to analyze and display their output.

3. *Suborbital and Spartan programs*. After some floundering during the mid-1980s, NASA's balloon program is currently fairly healthy, with the major problem being limited funding for instrument development. The rocket program has declined because funding has not kept up with inflation, active experiments were removed from the program, and funds were diverted to development of the Spartan program (a diversion with which the NRC concurred). The Spartan program effectively ended with the Challenger accident and, in retrospect, the resources expended for the Spartan program adversely affected the rocket-type science program it was meant to help.

Education

To date, only a few programs have set aside specific funds to support educational components of their activities. The CEDAR program has shown notable success in this area.

CONCLUSIONS

In summary, there has been considerable scientific progress during the past decade, with the bulk of the advances stemming from programs started in the 1970s, prior to the NRC recommendations considered in this report. Progress on the NRC recommendations of the 1980s has been generally slow, however, and in some cases nonexistent. Cancellations, long delays, and major programmatic restructuring have been routine. The perception is that initial responses have been positive but that actions in the implementation phases have not been carried through to achieve the goals embodied in the recommendations.

Because of these cancellations, delays, and stretch outs, the scientific goals and most of the specific recommendations for each of the subdisciplines remain valid. There is presently no need for a new set of scientific goals and priorities. The most recent NRC report that set out an implementation plan for solar and space physics was written in 1985. Although parts of that report are now obsolete, the CSSP/CSTR plans to review NASA's Strategic Plan currently under development rather than to develop an implementation strategy of its own at the present time. The federated committee also plans to further examine issues in the agencies' research and analysis programs.

3.2 Assessment of Programs in Space Biology and Medicine—1991

A Report of the Committee on Space Biology and Medicine

INTRODUCTION

This report was undertaken at the request of the Space Studies Board to provide an up-to-date assessment of the status of the implementation in the civil space program of the various research strategies and recommendations published in previous reports. This report limits its comments to information contained in the three most recent reports (SSB 1979, 1987, and 1988). The most comprehensive strategy was the report published in 1987, *A Strategy for Space Biology and Medical Science for the 1980s and 1990s* (SSB, 1987), edited by Jay Goldberg, University of Chicago. The Goldberg Strategy (as the 1987 strategy report is referred to in this report) forms the primary basis for the current evaluation, although reference is also made to several previous reports concerning life sciences by the Committee on Space Biology and Medicine (CSBM) and the Life Sciences Task Group of the Space Science Board that was part of the 1988 *Space Science in the Twenty-First Century* report. Space biology and medicine includes—in addition to biological and medical subdisciplines—human behavior, radiation, and closed ecological life support systems.

The Goldberg Strategy defined four major goals:

1. To describe and understand human adaptation to the space environment and readaptation upon return to earth.
2. To use the knowledge so obtained to devise procedures that will improve the health, safety, comfort, and performance of the astronauts.
3. To understand the role that gravity plays in the biological processes of both plants and animals.
4. To determine if any biological phenomenon that arises in an individual organism or small group of organisms is better studied in space than on earth.

The first two goals have taken on new emphasis since the announcement of the Space Exploration Initiative (SEI), enunciated by the President in July 1989, for a sequential progression of human activities in space, and extending potential human missions to years in duration. In discussing the major imperatives for research in space biology and medicine, this assessment of the implementation of the research strategies has categorized research topics relative to the urgency that would be dictated by proceeding with a space exploration initiative.

The conduct of research in space biology and medicine is influenced by the way the civil space agency, National Aeronautics and Space Administration (NASA), is structured and managed. Consequently, previous reports by CSBM have contained numerous recommendations concerning science program and policy issues. Because of the importance of these issues in approaching the various research goals, progress in implementation of these goals is discussed at the outset. This is followed by topics that have the greatest potential of affecting human performance and/or survivability during sustained space exploration. These topics include research areas concerning human physiology in microgravity, human behavior during long-term missions, and the radiation environments of space. Finally, the report contains sections on developmental and cell biology, human reproduction, plant biology, and issues associated with the development of a closed ecological life support system. The latter topics reflect areas that, while not deemed crucial to survival in space for durations of a few years, could become critical to longer-term human habitation. In addition, these topics represent major research areas in which space could be especially valuable in the study of basic biological phenomena.

SCIENCE PROGRAM AND POLICY ISSUES

Published strategy reports (e.g., SSB 1979, 1987, 1988) contain recommendations concerning how NASA manages its life sciences research and the design and utilization of laboratory space on a space station. In the area of management, recommendations were as follows:

1. Standing panels of 5 to 10 scientists should be created to review, update, and refine research strategies in each subdiscipline of space biology and medicine.
2. Announcements of Opportunity (AOs) and NASA Research Announcements (NRAs) concerned with Shuttle flights and the space station should be targeted to a particular subdiscipline and should state explicitly the major research questions that the mission is intended to address.

3. NASA should actively solicit the participation of other relevant federal agencies such as NIH and NSF in the design and conduct of research related to the major questions that need to be answered.

Recommendations related to a space station were as follows:

1. A space station should contain a dedicated life sciences laboratory, and research time should be allocated in 3- to 6-month increments for individual subdisciplines.
2. A variable force centrifuge of the largest possible dimensions should be incorporated into a space station.
3. Dedicated microprocessors should be used for process control, data storage, or both, and rapid communication in real time with ground-based research teams should be a goal.

In the area of management, NASA either has implemented or is in the process of implementing all of the recommendations made. The internal life sciences advisory structure has been reorganized as recommended. The NRAs that are now being released are more highly focused, and NASA is now actively cooperating with other federal agencies such as National Institutes of Health (NIH), National Science Foundation (NSF), and the U.S. Department of Agriculture (USDA), as well as numerous foreign partners.

None of the recommendations concerning design and utilization of the space station have been implemented in current plans for the facility; however, planning for inclusion of a centrifuge is under way.

RESEARCH IN SPACE BIOLOGY AND MEDICINE

Human Physiology

There has been a general perception that since a small number of Soviet cosmonauts have survived in the microgravity of space in low earth orbit for as long as a year, there are no major physiological problems likely to preclude longer-term human exploration beyond low earth orbit. The committee has had, over the years, access to anecdotal data from the Soviet space program. This anecdotal information is, while interesting, not sufficiently reliable for drawing conclusions or in planning the U.S. program for a number of reasons. There are differences in experimental protocols and controls in laboratory equipment, and the Soviets do not publish their results in refereed scientific journals. However, increased recent cooperative activities between the Soviets and the United States suggest promise for the future in standardized experimental procedures and data exchange.

The current evaluation of progress in space biology and medical research illustrates that all of the major physiological problems characteristic of prolonged human exposure to the microgravity environment of space remain unsolved. First, and of greatest concern, is bone, muscle, and mineral metabolism; second, cardiovascular and homeostatic functions; and third, sensorimotor integration.

Bone, Muscle, and Mineral Metabolism

Eight major goals were defined for the study of bone and mineral metabolism: (1) determine the temporal sequence of bone remodeling in response to microgravity; (2) establish the reversibility of this process on return to a 1-g environment; (3) establish the relationship between muscle activity and bone function; (4) devise countermeasures to prevent bone loss; (5) establish the cellular mechanisms responsible for bone loss; (6) evaluate the interdependence of calcium homeostasis and bone remodeling; (7) determine the etiology of pathologic calcification; and (8) establish the biomechanics of the skeleton under microgravity conditions.

Understanding the etiology of bone loss (osteopenia) is the focus of an enormous research program within the NIH as well as an area of research that has received major attention by NASA scientists—especially over the past 5 years. NASA scientists and others supported by NASA have developed an animal model to study bone loss. In addition, human studies correlating inactivity (bed rest) to factors such as diminished bone mass and increased urinary calcium have also proven to be useful models for potential changes during extended spaceflight. However, of the eight major goals listed above, only the first has been addressed in these studies, and the information that has been obtained using the animal model chosen (rat) is of limited value because of the dissimilarities between bone physiology in rats and normal human physiology. Considerable research remains to be conducted. Increased interaction with the major research effort at NIH would be of enormous value for solving the overall problems of bone and muscle atrophy that have been observed in microgravity.

Cardiovascular and Other Homeostatic Systems

The cardiovascular and neuroendocrine elements of the circulatory system focus respectively on basic cardiovascular function and the influences of regulatory systems on these functions. Additional areas under this topic include immunology, hematopoiesis, and wound healing.

Circulatory Adjustments—The major goals have been to (1) understand acute (0 to 2 weeks), medium-term (2 weeks to 3 months), and long-term (greater than 3 months) changes in the cardiovascular system in microgravity; (2) examine the validity of ground-based models of microgravity-induced changes; and (3) define measures (countermeasures) that will alleviate changes in microgravity and hasten human adaptation upon return to a 1-g environment.

A better understanding of cardiovascular and pulmonary physiology in microgravity has been a major goal of previous, current, and planned investigations. Measurements on humans before, during, and after several Shuttle flights have provided echocardiographic data on cardiac dimensions and function. Some countermeasures such as oral saline loading have been tested to prevent post-flight orthostatic hypotension. A major drawback has been the limited number of subjects available for study. There is a need to develop animal models for both ground-based and flight experiments. Hormones that affect the cardiovascular system also remain to be tested in the context of cardiovascular changes that occur in space. Some hormone measurements were conducted on Skylab flights, and additional studies are planned on upcoming Shuttle flights. However, many of these experiments fail to take into account fairly recent observations concerning the rhythmic nature of changes as a function of circadian variations.

Immunology—Immune cells in mammalian bone marrow and lymphoid organs initiate and regulate lymphocyte and antibody responses as well as control the production and function of cells in the blood and connective tissues. The major goal in this area is to determine if cells of the immune system can proliferate in space and maintain a normal immune system.

The occurrence of serious infections in space has been very uncommon, and most studies of immunity in space have been directed to the detection of abnormalities in human and animal lymphocyte numbers and morphology in space. Spaceflight is known to result in significant reductions of both plasma volume and red blood cell mass within days. Recent studies have shown that lymphocytes do not respond to stimuli that normally cause division, suggesting an impaired ability to proliferate in space. This could have profound implications for the immune and hematopoietic system. An expanded effort to investigate possible immune deficiencies coupled with the development of cell models to test immune and bone cell function in microgravity requires a higher priority.

Sensorimotor Integration

As indicated in the Goldberg report, the neuronal mechanisms underlying a sense of spatial orientation are complex, as yet poorly understood, and are directly relevant to assuring the effective functioning of humans involved in space missions. The 1987 strategy report recommended a vigorous program of ground-based and flight research aimed at understanding these mechanisms as they operate on earth, in space, and on return from microgravity to high-gravity environments. These studies become all the more significant if one considers the use of artificial gravity (rotating spacecraft) as an attempt to ameliorate the effects of microgravity on human physiology. Specific goals are to (1) study in microgravity how the vestibuloocular reflex (VOR) converts head motion into compensatory eye movement, (2) investigate the neural processing mechanisms in the vestibular system in both normal gravity and microgravity, (3) focus on adaptive mechanisms that alter vestibular processing in response to altered feedback from the environment, and (4) investigate more fully the etiology of motion sickness in microgravity.

Overall, NASA has made a concerted effort to undertake appropriate, quality research in the sensorimotor area. These efforts include many studies supported through external investigators and the establishment of an excellent Vestibular Research Facility (VRF) at Ames Research Center. In spite of limited flight opportunities, considerable progress has also been made studying sensorimotor performance in microgravity. Several planned experiments are promising. However, in spite of this generally positive view, no single countermeasure has yet been developed that corrects the problem of space motion sickness. Perhaps the syndrome, with individual variations, is actually several distinguishable syndromes. This possibility, if documented, might dictate new research approaches.

Behavior, Performance, and Human Factors

The major goals for space research as it relates to human behavior are to develop (1) spacecraft environments, (2) interfaces with equipment, (3) work-leisure schedules, and (4) the social organization that will optimize the efficiency, safety, and satisfaction of crews during long-term spaceflight.

With the exception of group and organizational factors, there is research in progress along the lines recommended in published research strategies. Much of the progress that has occurred derives from well-funded research programs in aviation sponsored by the Federal Aviation Administration (FAA) and to a lesser extent from NASA's aviation research program. However, this type of research, while useful, cannot provide all of the information needed to support a long-term human presence in space. As opportunities for experimentation that will exist during long-duration spaceflight will always be extremely limited, there must be a well-developed ground-based program of research employing a variety of research settings. At this point in time, NASA has no plans to develop long-term confinement studies using ground-based research settings.

Developmental and Cell Biology

The major goal for developmental biology as outlined in all three research strategies is to determine whether any organism can develop from fertilization through the formation of viable gametes in the next generation, i.e., from egg to egg, in the microgravity environment of space. In the event that normal development does not occur, the priority is to determine which period of development is most sensitive to microgravity. Potentially, research on specific developmental phases (e.g., fertilization to initial organ formation) would suggest detailed studies on the function and differentiation of individual cells or groups of cells. In approaching these goals, we have recommended studies on several representative organisms including both invertebrate and vertebrate animals. While the latter would include mammals such as mice, it also encompasses the question, can humans reproduce in space? The importance of these questions relates to the ability to establish permanent human colonies in space as well as to the possibility that the space environment could be a particularly advantageous environment to study basic developmental research.

A number of diverse organisms have been subjected to microgravity for varying periods of time. The results of these studies have been inconsistent. Both normal and abnormal development have been observed, dependent on the organism and the stage of development at which the material was subjected to microgravity. To our knowledge, no animal species has ever been carried through one complete life cycle in the microgravity of space.

Plant Biology

Any strategy that visualizes a long-term sustained human presence in space absolutely requires the ability to continuously grow and reproduce various plant species over multiple generations. A related goal, which has implications for agriculture generally, is to understand the mechanism(s) involved in gravity sensing by plants. This requires an emphasis on ground-based research as well as research in space.

For the most part, observations on plants exposed to microgravity have been anecdotal. It has been demonstrated repeatedly that plants do grow in microgravity. However, whether plants can grow normally remains to be determined. Significantly, results of studies on the German D-1 mission, which incorporated onboard 1-g centrifuge controls, indicate that single plant cells behave normally or even exhibit accelerated development. In contrast, the roots of seedlings germinated in microgravity grew straight out from the seed, and the same roots contained starch grains (statolyths) which were more or less randomly distributed in their cells. Control roots centrifuged at 1 g on the flight, were normally gravitropic.

Cytological studies of roots flown under a variety of conditions in space have consistently revealed reduced cell divisions as well as a variety of chromosomal abnormalities. At the same time, some Soviet experiments using the plant arabidopsis indicate that at least this plant develops normally through the flowering stage. However, in the Soviet experiments, fruit set was decreased and seeds brought back to earth germinated less efficiently than ground-based controls. Long-term flight experiments are required to determine if a variety of plant species can grow normally in microgravity and, in particular, if they can produce viable seeds.

Closed Ecological Life Support Systems

The closed ecological life support system (CELSS) program at NASA is attempting to create an integrated self-sustaining system capable of providing food, potable water, and a breathable atmosphere for space crews during missions of long-term duration. An effective CELSS must have subsystems both for plant and animal growth, food processing, and waste management. These have been described to some extent on previous pages. A CELSS must be much more than a "greenhouse in space." It must be a multispecific ecosystem operating in a small closed environment. Thus, although the concept is easily articulated, numerous areas of ignorance remain.

Based on consideration of primarily agricultural plant species, a small number have been selected for further investigation. These include wheat, potato, soybean, and tomato. Growth chamber studies have been initiated, both at NASA and in university laboratories, with the aim of defining the conditions required for optimum rates of dry matter production. Although most research has been done with open systems, experiments with closed systems have recently been initiated. No attention has been paid to the use of techniques of plant breeding or genetic engineering to "design" ideal plants for a CELSS system. No experiments have yet been performed in microgravity to determine if current systems can function in space. In short, a considerable increase in research efforts, and in support for those efforts, is required in order to reach the desired goals.

Radiation Biology

While the radiation environment within the magnetosphere is fairly well known, as are the biological effects of low energy transfer (LET) radiations from protons and electrons, considerably better quantitative data on LET dose rates beyond the magnetosphere are still required. In particular, better predictability of the occurrence and magnitude of energetic particles from solar flares is required; radiation from solar flares can be life-threatening in relatively short time periods. Major goals of radiation research are to quantify high-energy (HZE) particles in space and to understand the biological effects of HZE particles. The likely long-term biological effects of exposure to HZE particles is an increased incidence of cancer and brain damage.

NASA has maintained a limited but ongoing research program both in radiation dosimetry and radiobiology including ground-based programs on the effect of fragmentation of HZE particles and on the secondary particles. In the field of radiobiology, NASA has supported studies dealing with the biological effects of HZE particles. Limited flight data suggest a synergism between HZE particle hits and microgravity. This research requires increased attention. In particular, ground-based studies on biological effects of HZE particles are currently performed in the United States at the Billion Electron Volts Linear Accelerator (BEVALAC) at Lawrence Berkeley Laboratory. This research may be drastically curtailed if the facility is unavailable after 1993 as is currently planned. Use of similar facilities in other countries, while feasible, is not necessarily practical because of the necessity for transporting large numbers of animals and associated experimental controls, and regular transport and accommodation of U.S. research teams.

CONCLUSIONS

Over the past 30 or more years, the Space Studies Board and its various committees have published hundreds of recommendations concerning life sciences research. Several particularly noteworthy themes appear consistently: (1) ***balance***—the need for a well-balanced research program in terms of ground versus flight, basic versus clinical, and internal versus extramural; (2) ***excellence***—because of the extremely limited number of flight opportunities (as well as their associated relative costs), the need for absolute excellence in the research that is conducted, in terms of topic, protocol, and investigator, and (3) ***facilities***—the single most important facility for life sciences research in space, an on-board, variable force centrifuge.

In this first assessment report, the Committee on Space Biology and Medicine emphasizes that these long-standing themes remain as essential today as when first articulated. On the brink of the twenty-first century, the nation is contemplating the goal of human space exploration; consequently, the themes bear repeating. Each is a critical component of what will be necessary to successfully achieve such a goal.

3.3 Assessment of Solar System Exploration Programs—1991

A Report of the Committee on Planetary and Lunar Exploration

SUMMARY

The advisory base for the Committee on Planetary and Lunar Exploration (COMPLEX) is made up of a series of documents published over the last 15 years. These documents provide a rationale for planetary exploration, a strategy for carrying out scientific study of the solar system, and a series of recommendations to NASA for implementation of this strategy. This report reviews the recommendations of the committee and the status of the field of planetary exploration relative to those recommendations.

NASA's planetary exploration program has made great strides in the last few years. Much of the strategy for exploration of the planets proposed by COMPLEX has been implemented. Other areas await the arrival of planned or approved space missions at their targets. The rate at which the proposed scientific objectives would be achieved was in some cases overestimated by COMPLEX; these objectives still await fulfillment.

Significant scientific objectives have been achieved in exploration of the outer planets and comets. U.S.-European cooperation is proceeding well. Further exploration of Venus is under way and of Mars is imminent. In contrast, little progress has been made in more intensive study of the Moon and Mercury and in preliminary reconnaissance of asteroids and Pluto. Exploration on the surface of Venus, in the inner Jupiter magnetosphere, and in the deep atmospheres of the outer planets requires significant technical developments that should be undertaken. These developments include high-temperature and high-pressure instruments, radiation-hardened spacecraft, and development of low-thrust propulsion. The recommendations in the areas of detection and study of other solar systems and in exobiology research are so recent that it is premature to evaluate the status of current activities.

Areas of concern to the planetary science community include the absence of a plan to carry out the extended mission for Magellan, the lack of reserves in approved flight missions, and the inappropriate use of research and analysis funds as a reserve for mission overruns. The committee views positively the proposed planetary Discovery mission line and NASA's efforts to encourage interdisciplinary research.

3.4 Assessment of Satellite Earth Observation Programs—1991

A Report of the Committee on Earth Studies

SUMMARY

During the past decade, the Space Studies Board, its Committee on Earth Studies (CES), and other bodies of the National Research Council have provided the federal government with a substantial body of advice on the study of the Earth from space. Together, these documents have contained an overall strategy for science and applications using Earth observation spacecraft and have established a set of specific recommendations for implementation of the strategic advice. This report assesses the status of the nation's civil Earth observation programs in relation to this existing body of advice and provides additional advice on how to address the unfulfilled objectives and recommendations in the current scientific and programmatic context.

Specifically, the report reviews the content of the satellite Earth observation programs of the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), and the Landsat system operated by the Earth Observation Satellite (EOSAT) Company as of the spring of 1991. The NASA programs are within the agency's Mission to Planet Earth initiative, which includes the Earth Observing System (EOS) and its related data and information system, the Earth Probe small- and moderate-size mission line, and a number of "precursor" missions such as the Upper Atmosphere Research Satellite (UARS) and the Ocean Topography Experiment (TOPEX/Poseidon). The NOAA programs include the two meteorological satellite series, the Polar-Orbiting Operational Environmental Satellites (POES) and the Geostationary Operational Environmental Satellites (GOES). Also considered in this assessment are some of the Defense Department's operational and experimental spacecraft, including the Defense Meteorological Satellite Program (DMSP), the Global Positioning System (GPS), and the completed Geosat mission. Finally, because the U.S. programs should be viewed in the broader international context, the experimental, operational, and commercial satellite programs of other countries are also discussed briefly.

The committee has found that substantial progress has been made in recent years in the earth science programs of NASA, although many of the science objectives previously established by this and other science advisory committees have not yet been fully achieved. More importantly, a majority of past CES recommendations are expected to be addressed by the funded and planned missions and related research programs that have been proposed for this decade through the nationally and internationally coordinated U.S. Global Change Research Program (USGCRP) and Mission to Planet Earth. The committee concludes that with the implementation of Mission to Planet Earth, together with the planned modernization of the NOAA environmental satellite programs and the continuation of vigorous research and development of remote sensing and related technologies, the United States will ensure its leadership in Earth observations from space.

The committee has found NASA's plans for Mission to Planet Earth to be responsive to the scientific objectives and recommendations established in past NRC reports, with the exception of several shortcomings noted below and some additional ones expressed in the body of the report. Development of the EOS-A spacecraft and instrument complement, as well as the missions currently planned under the Earth Probe line, should proceed without delay in order to achieve the recommended science objectives. The committee also supports the instrument complement under consideration for EOS-B, but recommends that NASA carefully consider the optimum platform and orbit configuration in light of all scientific requirements.

For spaceborne studies of the atmosphere and climate, the most significant scientific objectives will be supported by the data collected by NASA and NOAA spacecraft. Substantial progress also has been made by NASA and NOAA programs in fulfilling the space-related scientific objectives for physical oceanography, cryospheric studies, studies of tectonic deformation and variations in the Earth's rotation, and certain aspects of global biology, ecology, and biogeochemical cycles. Particularly noteworthy are NASA's support of general research and analysis (R&A) programs in the earth sciences during the past decade in the absence of many flight programs, and the high-priority attention now given by that agency to data management.

Areas of scientific research where considerably less progress has been made with Earth observation spacecraft include hydrology, land-surface geology and vegetation, and the Earth's gravitational and magnetic fields. Research in the first two of these areas has been hampered largely by the high cost of obtaining data from commercially operated remote sensing systems such as Landsat. In the future, they would be further impeded by NASA's

delays in flying advanced land-surface sensors such as the Synthetic Aperture Radar (SAR) and the High-Resolution Imaging Spectrometer (HIRIS) under the EOS program. The continued development and earliest possible deployment of the HIRIS and SAR instruments would significantly improve our ability to perform process studies and research in those areas. Exclusive reliance on sun-synchronous polar-orbiting satellites in the EOS program would also be inadequate for monitoring a number of important processes—such as the Earth's radiative balance, the formation of clouds, and biological productivity—that vary extensively throughout the diurnal cycle. Insufficient progress in the study of the Earth's gravitational and magnetic fields has been due to the lack of specific flight opportunities, despite long-standing recommendations by the scientific community to address them. Maintaining an accurate reference system based on space geodesy techniques would be useful for monitoring long-term global change indicators such as mean sea-level change.

In meeting the goals of the Mission to Planet Earth and the USGCRP, the agencies still need to complete development of a comprehensive observational strategy that preserves long-term continuity of the highest-priority measurements and makes the best use of existing resources. In light of limited federal budgetary resources, the committee considers it important for NASA, NOAA, and their space agency partners to:

- Maximize observational coverage by (1) eliminating gaps in coverage of the electromagnetic spectrum through better coordination of their respective programs and (2) reducing redundancies, with the exception of those redundancies that either help maintain continuity of key measurements or that provide multiple observations of variables with significant diurnal variations.
- Mount a special effort to ensure the absolute calibration and intercalibration of all Earth observation instruments to the highest achievable accuracy.
- Formulate a backup plan to be implemented in case of an instrument failure, to help ensure continuity in long-term observations such as those planned for EOS. This strategy may consist of the generation of alternative geophysical parameters, albeit less effective ones, either from complementary EOS instruments or from sensors flying on other NASA, U.S., or foreign spacecraft.
- Develop a plan for the surface and in situ data-gathering technologies and programs that are needed to complement Earth observations from space. The NASA aircraft and suborbital programs should be an integral part of this plan.
- Continue to transfer historical data sets onto secure media and improve the maintenance of long-term data archives.

Both the development and implementation of this comprehensive observational strategy should be done in consultation with the scientific community.

The implementation of the EOS Data and Information System (EOSDIS) and related NOAA data management initiatives is crucial to the success of future earth science and environmental research. It is important for NASA to continue to develop existing "pathfinder" data sets in cooperation with NOAA, and to include the data sets that will be collected by the European Earth Remote-Sensing Satellite, UARS, and TOPEX/Poseidon for prototype studies in developing the EOSDIS.

The organizational emphasis on data systems and modeling in the recent reorganization of NASA's Earth Science and Applications Division is appropriate. The loss of identity of the traditional earth science disciplines, however, raises concerns that a balanced treatment among the disciplines may be difficult to maintain. The responsibilities of the new organizational units ought to be sufficiently broad to accommodate the requisite elements of the previous discipline structure.

The status of operational and commercial applications is in a less healthy state. Although NOAA's POES program is on track and progressing in the development of next-generation spacecraft and sensors, the agency's GOES series has encountered serious difficulties. The two-satellite GOES system is currently operating with only one spacecraft, and the development of the new GOES series, which is being carried out in conjunction with NASA, is severely over budget and behind schedule.

A number of instruments developed by NASA in the past, such as the Earth Radiation Budget Experiment scanner, the Coastal Zone Color Scanner, and the Total Ozone Mapping Spectrometer, have not been adopted by NOAA for operational implementation despite the demonstrated maturity of the technology and the well-recognized need for such continuous measurements. Although NASA and NOAA have reached a tentative agreement on the designation of several EOS instruments as "pre-operational," the framework of the eventual transfer has not been worked out and the agencies have not yet agreed on the future status of the important Moderate-Resolution

Imaging Spectrometer (MODIS) instrument. Past difficulties in transferring well-tested experimental instruments to operational status underscore the imperative for the federal government to arrive at a firm and comprehensive agreement on NASA's and NOAA's responsibilities, and on funding for the eventual transfer of key EOS instruments to a long-term monitoring program.

The transfer of the Landsat system from NOAA to the private sector in 1985 was premature and poorly executed. Significant doubts about the future of this important remote sensing asset remain, and existing policies appear to be ineffective in assuring the future continuity of Landsat observations. The integration of the Landsat data into the research framework of the Mission to Planet Earth and USGCRP is especially important.

Support of research and development of the applications of remote sensing data has been reduced substantially at NASA during the past decade. Although NOAA and the commercial sector have primary responsibility for operational remote sensing, NASA has a mandate for supporting research in, and development of, broader remote sensing applications. It is important for the agency to incorporate potential applications of EOS into its planning for the program, while preserving the primacy of the EOS program's scientific goals and objectives. These activities would best be coordinated with industry and with the commercial and government applications communities.

The text that follows expands on the issues and recommendations highlighted in this summary, and contains a number of additional suggestions for improving our nation's satellite Earth observation programs.

4
Letter Reports

4.1 On the Proposed Redesign of Space Station Freedom

The Space Studies Board sent the following letter and attached position statement to Adm. Richard H. Truly, Administrator of NASA, on March 14, 1991.

As you know, the research utilization of a manned U.S. space station has been a subject of considerable interest to the Space Studies Board since the inception of the program. In a letter to Mr. Beggs in 1983, the Board expressed reservations about the national requirement for a manned station for supporting space science, other than life science. Since that time, station planning and design have evolved rapidly.

Beginning in late 1990, and particularly after the release of the Augustine Report and its recommendations for development of a U.S. space station, two of the Board's discipline committees have become increasingly concerned about the research capabilities of the station as redesigned under the Congressional mandate. In addition, the Board itself has expressed concern as to whether the redesigned station will adequately support the research required to make important national decisions about long term human spaceflight. The Committee on Microgravity Research and the Committee on Space Biology and Medicine were briefed by space station officials on redesign ground rules and guidelines on January 10 and February 8 of this year, respectively. On February 28, the full Board was briefed on the preliminary results of the redesign study, with the chairmen and several key members of the two committees in attendance. The briefing officials from the space station office were most generous with their time and very frank in their discussions. We thank them for their efforts. Based on this briefing and on known research requirements cited in the attached assessment, the consensus of the Board was that the inadequacy of the redesign in its present state for research was sufficiently grave that a formal Board statement expressing these views to you was in order. Please note that the Board did not formulate and does not express any opinion on the engineering feasibility of the present redesign, nor does the Board address possible reasons other than space research for proceeding with the redesigned station.

Enclosed is the assessment that resulted from the deliberations of the full Board, reflecting the participation of the two discipline committees. I will be happy to discuss with you any questions you might have about the Board's conclusions or the supporting rationale. We all share a common commitment to a vigorous and forward-looking national civil space research program.

Signed by
Louis J. Lanzerotti
Chair, Space Studies Board

SPACE STUDIES BOARD POSITION ON PROPOSED REDESIGN OF SPACE STATION FREEDOM

Summary

The United States has contemplated for many years the construction of a space station that would further a variety of national goals, one of which is space science and applications. The recent report of the presidentially appointed Advisory Committee on the Future of the U.S. Space Program, chaired by Norman Augustine, recommended that the development of a U.S. space station with research facilities must give top priority to life sciences research, with microgravity research assuming a significant but secondary role.[1] The Board notes that this recommendation is fully consistent with the 1983 Space Studies Board position on the space station, as well as with the 1988 National Academy of Sciences/National Academy of Engineering report to then newly-elected President Bush.[2,3] In the judgment of the Board, Space Station Freedom, at the present stage of redesign, does not meet the basic research requirements of the two principal scientific disciplines for which it is intended: (1) life sciences research necessary to support the national objective of long-term human exploration of space, and (2) microgravity research and applications. This conclusion as to the station's research capabilities is based upon an assessment of its redesign as of March 1991.[4] Attachments 1 and 2 summarize the research requirements for space biology and medicine and for microgravity research and their relationship to the redesigned space station.

The Space Studies Board's membership is not constituted such that it can provide an engineering judgment on the feasibility of the redesign, and therefore has not done so.

Research Return on Taxpayer Investment

The Space Studies Board considered the quantity and quality of research that might be conducted on the proposed redesigned space station in the context of the level of investment that will be required to bring it to completion. The Board believes that neither the quantity nor the quality of research that can be conducted on the proposed station merits the projected investment. As redesigned, a maximum of $2.6 billion per year would be expended on the station to achieve an initial crew-tended capability by the mid-1990s, not including associated Space Transportation System and user costs.[5] Additional funding at a comparable rate of expenditure would be required to achieve a permanently occupied capability late in the decade. In the initial, crew-tended configuration, the redesigned station would be devoted primarily to microgravity research. Life sciences research unique to the space station would not begin until the end of the decade, when the permanently occupied configuration would be established. For comparison, the 1991 NASA budget allocates roughly $102 million to microgravity research. In other words, during each of the next five years, the amount of funding devoted to space station construction for microgravity research would be approximately 20 times the level of the current research program for this discipline. In addition, the monthly cost of constructing the redesigned station would approach the annual total funding devoted to both NASA's life sciences and microgravity science and applications division during the current fiscal year.

Space Research Requirements, Opportunities, and Alternatives

Life Sciences Research

The Augustine Committee recently concluded that the primary objective of a space station should be life sciences research.[6] The Space Studies Board strongly endorses the position that a space-based laboratory is

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[1] *Report of the Advisory Committee on the Future of the U.S. Space Program*, Superintendent of Documents (GPO) December, 1990.

[2] Space Science Board Assessment of the Scientific Value of a Space Station and letter to NASA Administrator James Beggs, September 9, 1983. *See also* Space Studies Board, Testimony to U.S. Senate Subcommittee on Science, Technology, and Space, May 10, 1990.

[3] *Toward a New Era in Space—Realigning Policies to New Realities—Recommendations for President-Elect George Bush*, Committee on Space Policy, NAS/NAE (NAP) 1988.

[4] Briefing to Committee on Microgravity Research, William Taylor, Chief Scientist, Space Station Freedom, January 10, 1991. Briefing to Committee on Space Biology and Medicine, William Taylor, Chief Scientist, Space Station Freedom, February 8, 1991. Briefing to Space Studies Board, William Raney, Special Assistant, Space Station Freedom, and John-David Bartoe, Deputy Director, Space Station Freedom Operations and Utilization, February 28, 1991.

[5] Conference Report 101-900, HUD and Independent Agencies, FY 1991.

[6] See footnote 1 above.

required to study the physiological consequences of long-term spaceflight.[7,8] The Board notes that many of the fundamental problems in life sciences research involve a long period of time for their pursuit and solution. In its present form, the redesigned space station does not provide the facilities required for such research. (See Attachment 1.)

Microgravity Research

In the judgment of the Board, the limited microgravity research that could be conducted on the redesigned space station as currently proposed does not merit the investment. If such funds were made available, the research community would likely choose to spend them in a very different way. (See Attachment 2.) The Board believes specifically that more research progress could be achieved in a shorter period of time and at a fraction of the cost through an expanded program of Spacelab missions and of free-flyer experiments.[9,10,11]

National Goals and Their Achievement

In conclusion, the SSB recognizes that there are national considerations for building a space station other than scientific research. Included among these are the possibilities of enhancing international prestige, stimulating the nation's educational achievement, stimulating the U.S. technology base, and supporting a long-term human space exploration initiative.

In the judgment of the Board, the proposed redesign of Space Station Freedom does not meet the stated national goal of enabling the life sciences research necessary to support extended human space exploration, nor does it meet the stated needs of the microgravity research community—most of whose goals could be achieved in both a more timely and more cost-effective manner by alternative means. Continued development of Space Station Freedom, as currently redesigned, cannot be supported on scientific grounds. If the present station redesign is implemented, this major national investment must be justified on the basis of considerations other than research in these two disciplines.

ATTACHMENT 1
SPACE BIOLOGY AND MEDICINE RESEARCH REQUIREMENTS

Requirements for conducting space biology and medicine research are described in detail in the 1987 report, *A Strategy for Space Biology and Medical Science for the 1980s and 1990s*.[12] The major goals established in that report for this area of research are:

a. "To describe and understand human adaptation to the space environment and the readaptation upon return to Earth."
b. "To use the knowledge so obtained to devise procedures that will improve the health, safety, comfort, and performance of the astronauts. Specifically, we must improve our understanding of the microgravity induced alterations in physiologic and psychological processes as well as effects of radiation before long duration human exploration can be safely and effectively pursued."

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[7] *A Strategy for Space Biology and Medical Science for the 1980s and 1990s* (NAP) 1987. *Space Studies Board Assessment: Space Biology and Medicine Research—1990* (in press). Space Studies Board/Committee on Space Biology and Medicine, letter to Andrew Stofan, Associate Administrator, Office of Space Station, NASA Headquarters, July 21, 1987. Space Studies Board/Committee on Space Biology and Medicine, Testimony to the U.S. Senate Subcommittee on HUD Appropriations, May 1, 1987.

[8] Space Studies Board letter to Joseph Alexander, Assistant Associate Administrator, Office of Space Science and Applications, NASA Headquarters, December 12, 1990. *Space Station Summer Study Report*, SESAC Task Force on Scientific Uses of a Space Station, NASA, March 21, 1985. *Space Station Summer Study Report*, SESAC Task Force on Scientific Uses of a Space Station, NASA, March, 1986.

[9] *Microgravity Science and Applications—Report on a Workshop*, Panel on Microgravity Science and Applications, Solid State Sciences Committee, Board on Physics and Astronomy (NAP) 1986. *Review of Microgravity Science and Applications Flight Programs*, Committee to Review the Microgravity Science and Applications Flight Program, USRA, January-March, 1987. Space Studies Board Workshop on Microgravity Research, NAS Beckman Center, January 16-17, 1989.

[10] *Materials Processing in Space*, Committee on Scientific and Technological Aspects of Materials Processing in Space, Space Applications Board (NAS) 1978. *Industrial Applications of the Microgravity Environment*, Space Applications Board (NAP) 1988.

[11] See footnote 8 above.

[12] See footnote 7 above.

Critical Requirements for Conducting Space Biology and Medicine Research

The Board's 1987 report[13] emphasizes that a space station is pivotal to the conduct of life sciences research, and it documents the following as critical requirements for a space station:

1. A dedicated life sciences laboratory with adequate scientific crew to conduct research.
2. A variable speed centrifuge of sufficient radius to accommodate small primates.
3. Sufficient numbers of experimental subjects (humans, plants, and animals) to address the stated scientific goals.
4. Sufficient laboratory resources, i.e., power, equipment, space, and atmosphere, to support the above research requirements.

The Space Studies Board's Committee on Space Biology and Medicine, and the Board itself wish to emphatically emphasize that the above requirements are absolutely fundamental to the acquisition of the data necessary to determine the feasibility of long-term human space exploration.

Inadequacy of the Redesigned Space Station Freedom for Space Biology and Medicine Research Requirements

The Committee on Space Biology and Medicine and the Space Studies Board conclude that Space Station Freedom, in its present redesigned form, will be inadequate to meet the requirements for space biology and medicine research described above because of the following:

1. The plan to share limited power among multiple users in all laboratory modules suggests that there will be insufficient power to conduct the volume of long-term biological experiments required to support a human space exploration initiative.
2. Plans for the size and location of a centrifuge and of animal-holding facilities are insufficiently defined for proper evaluation. As emphasized in the Board's 1987 strategy report,[14] an adequate centrifuge is essential to provide a 1-g control for 0-g experiments and *also* to explore the adequacy of artificial gravity for long-duration spaceflight.
3. The proposed crew size is insufficient to conduct the requisite experiments in a reasonable time period.
4. The absence of a dedicated life sciences laboratory will prohibit some experiments and will severely restrict most others, prolonging the acquisition of data required to answer fundamental questions related to the feasibility of long-duration human space exploration.

ATTACHMENT 2
MICROGRAVITY RESEARCH REQUIREMENTS

The National Research Council, as well as several NASA advisory committees, has published reports over the years that specifically address the minimum research requirements for this field of space research.[15,16,17]

The Space Studies Board's Committee on Microgravity Research has advised the Board that, unlike research in the field of space biology and medicine, only a limited amount of the desired research in microgravity, at least

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[13] *A Strategy for Space Biology and Medical Science for the 1980s and 1990s* (NAP) 1987. *Space Studies Board Assessment: Space Biology and Medicine Research—1990* (in press). Space Studies Board/Committee on Space Biology and Medicine, letter to Andrew Stofan, Associate Administrator, Office of Space Station, NASA Headquarters, July 21, 1987. Space Studies Board/Committee on Space Biology and Medicine, Testimony to the U.S. Senate Subcommittee on HUD Appropriations, May 1, 1987.

[14] See footnote 13 above.

[15] Space Studies Board letter to Joseph Alexander, Assistant Associate Administrator, Office of Space Science and Applications, NASA Headquarters, December 12, 1990. *Space Station Summer Study Report*, SESAC Task Force on Scientific Uses of a Space Station, NASA, March 21, 1985. *Space Station Summer Study Report*, SESAC Task Force on Scientific Uses of a Space Station, NASA, March, 1986.

[16] *Microgravity Science and Applications—Report on a Workshop*, Panel on Microgravity Science and Applications, Solid State Sciences Committee, Board on Physics and Astronomy (NAP) 1986. *Review of Microgravity Science and Applications Flight Programs*, Committee to Review the Microgravity Science and Applications Flight Program, USRA, January-March, 1987. Space Studies Board Workshop on Microgravity Research, NAS Beckman Center, January 16-17, 1989.

[17] *Materials Processing in Space*, Committee on Scientific and Technological Aspects of Materials Processing in Space, Space Applications Board (NAS) 1978. *Industrial Applications of the Microgravity Environment*, Space Applications Board (NAP) 1988.

over the next decade, can best be accomplished with a space station. The use of crew-tended free-flyers, drop towers, extended duration Spacelabs, and so forth, offer adequate, and in fact more viable, opportunities for the research needs in many cases. There are, however, important experiments requiring measurements and human observation and interaction over extended periods of time. The space station is a means to provide this capability. If plans proceed to conduct microgravity research on the redesigned Space Station Freedom, the Board and its Committee on Microgravity Research recommend that adequate provisions be made for supporting only those microgravity research questions that can best be addressed using a space station.

The following minimum facility requirements for microgravity research aboard a space station are based on the conclusions and recommendations described in the cited reports and on recent briefings presented to the Committee on Microgravity Research and the Space Studies Board.[18]

Critical Requirements for Conducting Microgravity Research on a Space Station

1. Adequate power, research volume, and support space.
2. Skilled on-board scientific personnel in sufficient numbers to carry out experiments and to diagnose and correct malfunctions.
3. Suitable acceleration environment and adequate monitoring.
4. Affordable de-integration and re-integration of experiments on orbit.
5. Capability to integrate advanced techniques and instrumentation as these become available.
6. Fast turnaround for specimens that must be characterized on Earth.

Inadequacy of the Redesigned Space Station Freedom for Microgravity Research Needs

The redesigned Space Station Freedom would be inadequate to meet the requirements of microgravity science and applications because it lacks the following:

1. A low, quiescent acceleration environment unhampered by crew activities, docking maneuvers, and other system activities necessary to sustain a permanently occupied presence.
2. A crew that would spend sufficient time working with the experiment equipment (see Attachment 1, item 3).
3. Sufficient power, data-handling capabilities, and research volume (see Attachment 1, item 1).
4. The flexibility to upgrade systems; this deficiency is especially disconcerting in the area of computers, in which obsolescence is extremely rapid.

Other Issues

During the crew-tended phase, NASA plans to fly Spacelab experiment hardware on the Space Station Freedom because other, newer hardware will not be available. Most of this Spacelab hardware will require manual intervention and therefore will be operable only when people are present. Unfortunately, the crew-tended phase is a time when significant acceleration disturbances will exist due to concurrent hardware integration and assembly and construction activities. Therefore, the man-tended phase will not be suitable for many microgravity experiments. Only a limited number of experiments could be run during the free-flying mode between shuttle visits during the crew-tended phase.

If the bulk of the microgravity research program planned for Freedom were removed, the station would then be devoted almost exclusively to life sciences research. The benefits of this action would be that (a) the g-level on the station would not have to be strongly controlled, thus resulting in significant cost savings, (b) some low-gravity experiments (e.g., fluids handling, fire safety) could still be done on the space station, and (c) the bulk of the microgravity program could be conducted using independent, more cost-effective facilities.

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[18] Briefing to Committee on Microgravity Research, William Taylor, Chief Scientist, Space Station Freedom, January 10, 1991. Briefing to Committee on Space Biology and Medicine, William Taylor, Chief Scientist, Space Station Freedom, February 8, 1991. Briefing to Space Studies Board, William Raney, Special Assistant, Space Station Freedom, and John-David Bartoe, Deputy Director, Space Station Freedom Operations and Utilization, February 28, 1991.

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4.2 On the NASA Earth Observing System

The Space Studies Board sent the following letter and attached position to Adm. Richard H. Truly, Administrator of NASA, on July 10, 1991.

We are pleased to transmit to you two new Space Studies Board reports: *Space Studies Board Position on the NASA Earth Observing System,* and a prepublication copy of a related report, *Assessment of Satellite Earth Observation Programs—1991,* by the Board's Committee on Earth Studies. We will forward a bound copy of the latter report as soon as it is printed.

Copies of these reports will be sent to cognizant executive agency and congressional offices tomorrow morning and subsequently to the media. Do not hesitate to call me if you have any questions about either of these reports.

Signed by
Louis J. Lanzerotti
Chair, Space Studies Board

SPACE STUDIES BOARD POSITION ON THE NASA EARTH OBSERVING SYSTEM

Introduction

Complex scientific questions and major policy issues together provide the motivation for a comprehensive attempt to improve our understanding of the earth system. Progress in the scientific disciplines concerned with the Earth and its evolution on time scales of decades to centuries has revealed critical questions that can be resolved only by studying the entire system, concentrating especially on interdisciplinary questions that reflect the complex interactions among the system's components. Policy issues arise because human activities and natural processes are changing the environment in ways that may be significant to the future health and habitability of the Earth. The scientific and policy issues have been well documented in a series of National Research Council (NRC) and government reports over the past decade.

These factors and the need for accurate and comprehensive scientific information on which to base environmental policy decisions have led to the creation of a number of international and national research initiatives, including the U.S. Global Change Research Program. According to the report *Our Changing Planet: The FY 1992 U.S. Global Change Research Program,* by the federal interagency Committee on Earth and Environmental Sciences (1991),

> The central goal of the U.S. Global Change Research Program (USGCRP) is to establish the scientific basis in support of national and international policy making relating to natural and human-induced changes in the global Earth system by:
>
> - Establish[ing] an integrated, comprehensive, long-term program of documenting the Earth system on a global scale.
> - Conduct[ing] a program of focused studies to improve our understanding of the physical, geological, chemical, biological and social processes that influence Earth system processes; [and]
> - Develop[ing] integrated conceptual and predictive Earth system models. (p. 1)

Even before the creation of the USGCRP in 1989, these considerations motivated the community of earth scientists concerned with global change to develop plans for research, observation, and modeling activities to improve scientific understanding. At the center of this set of activities was the Earth Observing System (EOS), a major initiative that has now been incorporated into the USGCRP. As currently proposed, EOS will involve a number of spacecraft carrying instruments designed to produce, across a wide spectrum of electromagnetic frequencies, detailed observations of the physical variables that reveal the state, evolution, and interactions of the atmosphere, oceans, and land surface, as well as the biological communities on the land and in the sea. The EOS program is planned to span almost two decades, beginning with the launch of the first spacecraft in 1998. It will generate unprecedented amounts of data that must be converted into information and understanding, and ultimately, used to develop techniques for prediction. These complex data management functions will be performed

through the EOS Data and Information System (EOSDIS), which will provide computing and networking facilities for research; processing, distribution, and archiving of EOS and related data; and spacecraft command and control functions. In addition to developing the flight components and the EOSDIS, the EOS program also supports interdisciplinary research teams, 28 of which are already established, to study focused issues that range across the relevant earth-related sciences. Other nations, notably Japan, Canada, and the member states of the European Space Agency, have made commitments for significant contributions to the total EOS program, including instruments and ground facilities. In short, EOS, as currently planned, will be the largest single component of the most ambitious scientific enterprise ever undertaken.

Nevertheless, there are observations critical to understanding the earth system that cannot be obtained by the instruments proposed for the polar-orbiting, sun-synchronous EOS spacecraft. Thus EOS itself is considered by NASA to be part of a broader satellite remote sensing initiative—Mission to Planet Earth—that will augment EOS with a number of focused missions, called Earth Probes, in other orbits. Possible missions under consideration include measurements of the Earth's radiation budget, an accurate determination of global land-surface topography, synthetic aperture radar observations of the Earth, and measurements of the Earth's gravity and magnetic fields. NASA plans that Mission to Planet Earth will eventually include geosynchronous satellites taking continuous synoptic observations of the planet. Several other NASA research missions being prepared for launch prior to the EOS time frame, such as the Upper Atmosphere Research Satellite and the Ocean Topography Experiment (TOPEX/Poseidon), also will make important contributions to our understanding of the Earth.

These elements of NASA's Mission to Planet Earth are or will be augmented significantly by the operational environmental spacecraft of the National Oceanic and Atmospheric Administration (NOAA) in polar and geostationary orbits, by the Landsat system operated on a commercial basis by the Earth Observation Satellite (EOSAT) Company, as well as by certain declassified data from operational and experimental satellites of the Department of Defense. Internationally, there are numerous experimental, operational, and commercial spacecraft already in orbit or under construction by the European Space Agency and its individual member states in western Europe, and by Canada, Japan, the Soviet Union, China, and India that can be expected to contribute to the global research and monitoring effort.

Scientific Significance of the EOS Program

The scientific questions motivating and shaping studies of the Earth generally, and the EOS program specifically, are very challenging. They are different in some respects from the questions that motivate much of space research, for they concern the behavior of an entire complex system, the role of feedback and interfacial processes in controlling its evolution, and the development of parameterizations that can be used to make long-term statistical projections. It will take several decades, at least, to answer these questions with confidence, even though the elements of critical policy issues may become clear much sooner.

Based on the research priorities established by the earth science research community, NASA (1991) has articulated the following specific measurement objectives for EOS in the *EOS Reference Handbook—1991:*

- Global distribution of energy input to and energy output from the Earth.
- Structure, state variables, composition, and dynamics of the atmosphere from the ground to the mesopause.
- Physical and biological structure, state, composition, and dynamics of the land surface, including terrestrial and inland water ecosystems.
- Rates, important sources and sinks, and key components and processes of the Earth's biogeochemical cycles.
- Circulation, surface temperature, wind stress, sea state, and the biological activity of the oceans.
- Extent, type, state, elevation, roughness, and dynamics of glaciers, ice sheets, snow, and sea ice.
- Global rates, amounts, and distribution of precipitation.
- Dynamic motions of the Earth as a whole, including both rotational dynamics and the kinematic motions of the tectonic plates.

Not all of these scientific objectives will be fully addressed in the EOS program, however. These and other deficiencies in the planned observations are discussed in the Space Studies Board's Committee on Earth Studies report, *Assessment of Satellite Earth Observation Programs—1991* (Space Studies Board, 1991), as well as in *The U.S. Global Change Research Program: An Assessment of FY 1991 Plans* (National Research Council, 1990).

In addition to the many contributions to the traditional earth sciences now expected, the EOS program will

have other significant impacts. It will stimulate the development of the new earth system science that transcends today's discipline-specific emphasis on components of the earth system and that produces a truly global view and comprehensive understanding of our planet. There will be strong impacts on the evolution of biological and ecological sciences, because the development of explicit models of the interaction of biological systems with the physical environment will be pursued. The EOS program is designed to provide an empirical base of information about the distribution and large-scale evolution of biological systems that may be expected to inspire the development of a theoretical understanding of macroscopic biology.

Moreover, understanding the interactions of all the components of the earth system could provide a prototype for the development of a theory of dynamical systems considerably richer than is now available. Among the most interesting issues are the interactions of processes on diverse spatial and temporal scales, the origins of catastrophic transitions between quasi-stable states of the system, and the characteristics of a system that determine its limiting behavior. The earth system models that will evolve from global data are also expected to stimulate the development of techniques for predicting the statistics of chaotic states for which deterministic prediction is impossible. Finally, the earth system computer models used to simulate future climate patterns and other large-scale processes will permit socioeconomic studies that require quantification of human interaction with the environment.

EOS in the Broader Context

As proposed, EOS is of unprecedented complexity and magnitude for two reasons. First, meeting the scientific requirements to observe and understand the interactions of earth system components requires integrated, and in some cases simultaneous, measurements of suites of variables. Thus the science requirements mandate spatially comprehensive observations of the Earth that produce information relevant to a broad spectrum of questions. Second, the importance of the policy issues associated with the possibility of accelerating global change requires that many elements of the observation program be developed through parallel, rather than incremental, endeavors. This approach must be managed with both innovation and rigor to ensure that each component of the proposed EOS program will be successful and that the program will achieve its objectives within a reasonable and well-defined cost.

Even so, the resources for EOS, as currently proposed, could become a significant fraction of the nation's civil space research program. There is an obvious danger that other important U.S. research initiatives may be compromised by the demands of EOS. The board notes that a 1988 NRC report, *Toward a New Era in Space—Realigning Policies to New Priorities,* and the *Report of the Advisory Committee on the Future of the U.S. Space Program* (NASA, 1990) both recommended that major NASA programs such as EOS and the human exploration of space be considered and evaluated as additions to a base space research effort. The SSB reaffirms this recommendation.

The national resources required to execute the proposed EOS program will be considerable, and there must be confidence that the investment will produce the achievements that are now expected. The EOS program will provide information and knowledge that could be used to address a number of concerns related to national well-being. The EOSDIS, in particular, will provide the capability to synthesize information for a broad range of applications, including the preservation of diverse ecosystems, the enhancement of agricultural productivity, and the improved management of our natural resources. The EOS program can help strengthen national and global security, in part because it will provide a significant portion of the scientific basis with which to address the potentially contentious political and economic issues related to human influences on global change, and in part because it will draw scientists and others from around the world to work in concert to understand, preserve, and perhaps improve our environment.

There are other benefits that could flow from EOS. It will stimulate the development of technological capability and new approaches to the management of large and complex collections of data and information. As an international effort, EOS can symbolize U.S. leadership in addressing global environmental problems. The sensors of the EOS program that are aimed at studying the Earth's surface and troposphere can augment current operational spaceborne systems. The necessary interfaces of the EOS program, with the relevant government agencies and the appropriate private-sector users, must be an integral part of EOS program planning if the broader applications of EOS data are to be realized. Given the planned long duration of the EOS program, such sensors may in some cases become the operational systems of choice, once their capabilities have been demonstrated.

Conclusions and Positions

The Space Studies Board (SSB) position on the EOS program is based in part on an analysis performed by its Committee on Earth Sciences (CES) in an unpublished internal report to the board, as well as on the committee's full report, *Assessment of Satellite Earth Observation Programs—1991* (Space Studies Board, 1991). This assessment by the board also takes account of the conclusions and recommendations described in *The U.S. Global Change Research Program: An Assessment of FY 1991 Plans* (National Research Council, 1990), and other previous reports of the SSB and the NRC cited in the bibliography.

In conducting this review, the SSB did not evaluate the cost-effectiveness of the proposed EOS program or compare it to other potential options. The board accepts the conclusions and recommendations on these issues made in the report, *The U.S. Global Change Research Program: An Assessment of FY 1991 Plans,* in the preparation of which members of the board and its Committee on Earth Studies played an active part. The board notes as well that questions of cost and comparisons to other mission scenarios are currently being independently reviewed by the Earth Observing System Engineering Review Advisory Committee, at the request of the Office of Management and Budget.

The conclusions and positions presented in this position paper simultaneously inspire confidence and generate concern. Clearly, the planners of the EOS program are attempting to incorporate the advice and key recommendations of the research community. As it now stands, the program serves well the scientific strategies recommended by the SSB and other advisory bodies. But EOS is an immense undertaking, and there are aspects of it that are not, and cannot be, completely determined or envisioned now. The flight configurations and the design of the data and information system are not yet fully defined. Moreover, the management of EOS must be sufficiently flexible to take advantage of continuing evolution over the program's lifetime in scientific understanding and requirements, and in technological capabilities. There is concern that the present program does not institutionalize such flexibility. The scope of the program will require the development and implementation of sophisticated and innovative management principles and structures at the project, agency, interagency, and international levels. These issues are all significant, because answers to the scientific questions that drive EOS are central to understanding, and possibly ameliorating, global change and its impacts.

The Space Studies Board concludes that the EOS program is a potentially valuable initiative to serve the best interests of science and the nation. The component parts of EOS together address complex scientific questions whose answers are important for establishing the most effective and appropriate policies related to global change. Because of the high priority of the overall science objectives that will be addressed by the EOS program, the rationale for flying suites of instruments that will measure these objectives, and the potential importance of the effects of global change on humanity, the SSB endorses the program. The acquisition of a long-term, continuous, and integrated series of data on the components of the earth system and their interactions is the critical scientific motivation for EOS.

Nevertheless, many important issues regarding EOS still exist and must be satisfactorily addressed in the months and years ahead. These concerns are related to matters involving (1) the development of the spacecraft configurations required for acquisition of the scientific data; (2) the design and evolution of the data and information management system; and (3) the long-term management plan to ensure program success for the planned scientific, applications, and policy purposes. After reviewing the documents prepared by the Committee on Earth Studies and the other reports cited above, the board has adopted the following conclusions and positions at this time:

- While parts of the EOS program require substantially more definition than is available at present, the SSB concludes three things about the planned implementation. First, a set of integrated instrumentation directed toward the highest-priority science is required. Second, scientific and technological evolution in the program must be implemented in a way that preserves the long-term continuity of the measurements. Third, the instrumentation selected for development for the second series of spacecraft proposed by NASA should be justified by the scientific objectives, but NASA should consider the optimum spacecraft and orbit configuration in light of all the scientific requirements.
- NASA and the scientific community should continue to examine the conceptual and architectural structures for the EOS Data and Information System (EOSDIS) to ensure that it will effectively serve the science and applications communities, that it will stimulate research and education in the sciences concerned with global change, and that it will be configured to take advantage of evolving technological capabilities.

- NASA and other entities of the federal government should give continuing attention to the optimum structures and policies for managing the EOS program. The scope and significance of the program, as well as its role as a key component of the U.S. Global Change Research Program, present a major management challenge. As it develops and proceeds, EOS can be strengthened through continuing review by the earth science and space research community.
- Management of the EOS program should institutionalize the flexibility necessary to accommodate evolution in understanding of the key scientific questions, and in technological capabilities for observation of the Earth from space. A process should be established so that EOS can take advantage of changes in spacecraft designs, instruments, and telemetry and communication systems, as well as in the hardware and software used in the data and information system, without sacrificing the central objective of collecting long-term, continuous data sets.
- Planning for EOS should continue to take specific account of the possibilities of failure in the components of the flight and communication systems. The EOS architecture and design should provide sufficient redundancy and flexibility to create alternatives that can be activated to mitigate the effects of failures and provide for continuity in observations. Provisions should be considered for in-flight reprogramming of the critical parts of spacecraft, instruments, and onboard control and data systems.
- The federal Committee on Earth and Environmental Sciences should carefully exercise its responsibility to ensure that EOS is integrated with the other components of the U.S. Global Change Research Program and other relevant federal programs, including the operational satellites of the National Oceanic and Atmospheric Administration, to maximize the effectiveness of all aspects of the research.
- Much more attention should be devoted to the issue of how to transfer the new scientific understanding to the federal and private organizations that will develop, and be affected by, policy decisions that might arise from the research results. In particular, NASA should ensure that the EOSDIS is designed and organized to facilitate dissemination of the knowledge gained from EOS to federal agencies and private organizations, and should assist in the effective conversion of this information into sound policy decisions.
- NASA should encourage the use of appropriate EOS data for applications in the operational and private sectors once the sensors have been validated in flight, and initial planning should involve those sectors. Research into the applications that will be made possible with the information derived from the new suite of EOS sensors should be supported by NASA and other federal agencies involved in such applications.

The EOS initiative must be viewed not as a project to construct and launch a number of spacecraft, but as a process to create a national and international capability for observing the Earth and providing the data and information necessary to address critical scientific questions. A number of important unresolved issues involving EOS science and system configuration still remain. The Space Studies Board will therefore continue to review the EOS program as it progresses.

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4.3 On Research Uses of LANDSAT

The Committee on Earth Studies sent the following letter to Dr. Shelby Tilford, Director of NASA's Earth Science and Applications Division, and Mr. Russell Koffler, NOAA Deputy Assistant Administrator of the National Environmental and Space Data and Information Service, on September 12, 1991.

At the May 1991 meeting of the Space Studies Board's (SSB) Committee on Earth Studies (CES), there was an extensive discussion of the current status and future uncertainty regarding the Landsat program. At that meeting, several invited participants from the government, notably from the Office of Management and Budget, and from the House Committee on Science, Space, and Technology, expressed an interest in receiving the views of the CES on the research applications of the Landsat program and its role in the broader satellite Earth observations context. This letter provides a focused analysis based in large part on the previous advice given on this program by the CES, SSB, and other National Research Council (NRC) advisory groups.

The Terms of Reference for this report are to:

1. review the research uses of the Landsat program, referring both to past examples and future needs;
2. examine the research role of the Landsat program in the broader land remote sensing context;
3. identify the difficulties associated with the effective use of Landsat data for research; and
4. provide recommendations for addressing those difficulties.

The committee has been informed that the House Committee on Science, Space, and Technology is planning to introduce legislation regarding the Landsat program in mid-September, and a decision regarding the future of Landsat is expected to be made by the National Space Council and the Office of Management and Budget before the end of September. Given the short schedule for the committee's review, this letter is limited to issues directly related to the basic and applied civil research uses of Landsat and draws heavily on past NRC advice. The rest of this letter is organized according to the Terms of Reference set forth above, and the committee's summary conclusions and recommendations appear in the final section.

RESEARCH USES OF LANDSAT

For almost twenty years the Landsat program has documented both natural and anthropogenic changes on the world's land surface. An uninterrupted stream of observations has provided revealing images—almost three million to date—of the natural environment and the effects of our actions upon it. The many important uses of Landsat have been well documented, most recently at a congressional hearing, on "Military, Civilian, and Commercial Applications of the Landsat Program," held jointly by the House Committee on Science, Space, and Technology and the Permanent Select Committee on Intelligence on June 26, 1991 (referred to below as the "joint hearing"). In this section the Committee briefly reviews the research applications of the Landsat system, primarily as they have been discussed in earlier NRC reports.

Basic Research

As discussed in past SSB reports, Landsat data have been used to support high-priority basic research objectives in geology, hydrology, glaciology, global biology, ecology, and biogeochemical cycles. Additional research areas in which the Landsat program has been instrumental, but that were not covered in the SSB reports, include agronomy, forestry, geography, and soil science.

Landsat data are important to achieving the primary science objectives for continental geology from space, which were established by the CES in its report, *A Strategy for Earth Science from Space in the 1980's—Part I: Solid Earth and Oceans* (Space Science Board, National Academy Press, Washington, D.C., 1982). These objectives, which remain valid today, are (1) to determine the global distribution and composition of continental rock units; (2) to determine the morphology and structural fabric of the Earth's land surface; and (3) to measure temporal changes in geological conditions at the Earth's surface.

Landsat observations have been and continue to be used to address some of the research objectives for the related areas of hydrology and glaciology, as proposed by the committee in *A Strategy for Earth Science from Space in the 1980's and 1990's—Part II: Atmosphere and Interactions with the Solid Earth, Oceans, and Biota*

TABLE 1 Major Characteristics of Selected Land Remote Sensing Systems

	Landsat-6 U.S.A.	SPOT France	MOS-1,2 India	IRS-1,2 India	JERS-1,2 Japan (1992)	ADEOS Japan (1995)
Visible/Near-Infrared Bands	5	3	4	4	3	5
Shortwave Infrared Bands	2	1 (SPOT-4, 1995)	(none)	(none)	4	(none)
Thermal Infrared Bands	1 (120 m)	(none)	(none)	(none)	(none)	(none)
Spatial Resolution of Images	15 m 30 m	10 m 20 m	50 m	36 m 73 m	18 x 24 m	8-16 m
Swath Width	185 km	60-80 km	100 km	148 km	75 km	80 km
Equatorial Crossing Time (+/- 15 mins)	10:30 a.m.	10:30 a.m.	10:30 a.m.	10:30 a.m.	10:30 a.m.	10:30 a.m.
Repeat Cycle	16 days	26 days (1-5 days with pointing)	17 days	22 days	44 days	41 days
Orbital Inclination	98.2°	98.7°	99.1°	polar	98°	98.6°

Notes: SPOT - Satellite Pour l'Observation de la Terre
MOS - Marine Observation Satellite
IRS - Indian Remote Sensing Satellite
JERS - Japanese Earth Resources Satellite
ADEOS - Advanced Earth Observing Satellite
Years in parentheses indicate planned launch dates.

(Space Science Board, National Academy Press, Washington, D.C., 1985). These objectives have included, in particular, the measurement of various land-surface characteristics that control hydrologic responses and are affected by hydrologic change, as well as the horizontal extent of the world's snow and ice cover.

Perhaps most importantly, Landsat data have been used extensively for the study of global biology, ecology, and biogeochemical cycles. In particular, the committee's 1985 report and another report, *Remote Sensing of the Biosphere* (Committee on Planetary Biology, Space Science Board, National Academy Press, Washington, D.C., 1986), identified several objectives for research on land-surface vegetation and the study of wetlands for which Landsat observations have been especially well suited. These objectives include the measurement of total area covered and the geographic distribution of major biomes and coastal wetlands, and measurement of the rate of change of distribution of major biomes and of annual vegetation production.

A survey of citations in seven databases performed by our committee in August 1991 showed that since 1972, the Landsat program and its data have been discussed in over 13,000 research articles in a broad range of disciplines. The databases surveyed were those of the National Technical Information Service and the Public Affairs International Service, as well as Georef, Geobase, Environmental Bibliography, Meteorological/Geoastrophysical Abstracts, and Water Resources Abstracts.

With regard to basic scientific research needs in the future, the Landsat program has provided an irreplaceable two-decade data set on land-surface processes, which is of critical importance to the U.S. Global Change Research Program (USGCRP) and the International Geosphere-Biosphere Program (IGBP). As noted in the committee's most recent report, *Assessment of Satellite Earth Observation Programs—1991* (Space Studies Board, National Academy Press, Washington, D.C., 1991), the effective "integration of the Landsat data into the research framework of the [NASA] Mission to Planet Earth and USGCRP is especially important." The Landsat program provides a baseline database that can be used to detect signal changes and climate change impacts to the land surface on regional scales. The importance of Landsat data to global change research was underscored by the testimony of Dr. Robert Corell, assistant director for geosciences at the National Science Foundation and chairman of the interagency Committee on Earth and Environmental Sciences' (CEES) Working Group on Global Change, at the joint hearing.

Applied Research

The program has also had a major impact in applied research. In a report of the NRC's Space Applications Board (SAB), *Remote Sensing of the Earth from Space: A Program in Crisis* (Space Applications Board, National Academy Press, Washington, D.C., 1985), the SAB found that "the Earth remote sensing [Landsat] program has demonstrated that the timely acquisition of data from satellites can result in significant social, economic, and scientific benefits," and that the "potential for the future is even greater." The report documented a number of representative examples of the applications of Landsat data and recommended that "Earth remote sensing should be an established and significant part of the nation's civil space enterprise."

Landsat data have become increasingly important in applied research and in the rapidly growing use of Geographic Information Systems (GISs). The far-reaching potential for use of Landsat data in environmental protection, resource management, and numerous socioeconomic applications was amply documented at the joint hearing in the testimony given by Dr. Dallas Peck, director of the U.S. Geological Survey; David Thibault, executive vice president of the Earth Satellite Corporation; Steven Sperry, manager of marketing at ERDAS, Inc.; and Lawrence Ayers, vice president for International Marketing at Intergraph Corp.

In summary, the committee concludes that Landsat observations have provided invaluable environmental information important for both basic research and applications, that the needs and uses for these data have grown steadily, and that they may be expected to continue to increase in the future. Moreover, as discussed in the next section, the Landsat system's capabilities have not been duplicated by other remote sensing systems, nor will they be replaced by any planned system—U.S. or foreign—before the end of the decade.

LANDSAT IN THE BROADER LAND REMOTE SENSING CONTEXT

Although the existing and potential applications of Landsat data provide a compelling incentive for the future continuation of the program, it is important to understand the role of the Landsat system in the overall land remote sensing context. Just as there have been significant advances in and expansion of the basic and applied research uses of Landsat, there have been concomitant advances in land remote sensing technologies and programs, not only in the United States, but internationally. The current and planned land remote sensing systems are reviewed here and compared with the Landsat-6 system, which will fly a Thematic Mapper with 30-m resolution and an Enhanced Thematic Mapper with 15-m resolution.

Table 1 provides a summary of all current and planned land remote sensing capabilities comparable to those of Landsat-6 that are expected to be launched prior to the launch of the NASA Earth Observing System (EOS) in the latter part of this decade. Not included in this comparative overview are lower-resolution sensors such as the Advanced Very High Resolution Radiometer onboard the NOAA polar-orbiting operational environmental spacecraft, or airborne and Shuttle-operated land remote sensing systems. These types of sensors are considered complementary rather than comparable, because of either lower resolution, or limited geographic or temporal coverage. Also not included in this list are several Soviet systems, some of which have high spectral and spatial resolution, but whose data are not available at this time on a consistent basis or in a digitized format.

As Table 1 indicates, there are at least five other land remote sensing systems, with sensors observing in the visible to infrared portions of the spectrum, that will be operating in the time frame of Landsat-6 and its immediate successor. Each of these systems shares several characteristics with Landsat-6, but none is identical. The other systems differ most significantly in their complete lack of thermal infrared coverage, their narrow swath widths, and, for the JERS and ADEOS systems, long repeat cycles. Thermal infrared observations provide data on surface geology, soil moisture, flooding, water temperature, and coastal currents. Landsat also has better shortwave infrared coverage than all but the planned JERS system. These bands are important for observing, among other things, vegetation characteristics such as biomass, plant stress, and deforestation. The broader swath width (and reduced spatial resolution) of Landsat makes it less costly to acquire and process data for large geographical areas. Finally, only the SPOT series can provide more frequent and timely coverage than Landsat because of SPOT's pointable sensor capability.

Although the technical comparison of Landsat to the other pre-EOS land remote sensing systems demonstrates its unique features, the most important features are not technical. The Landsat program has archived data for 13 years longer than has the second-oldest system, SPOT, and it therefore offers the longest uninterrupted satellite data set for global change research. The other systems' data sets, while partially analogous, are not

directly intercomparable with Landsat data. Even more importantly, all the other high-resolution, land-remote-sensing systems are operated by other nations, which means that the U.S. government and research community have only an indirect influence on the technical, programmatic, and policy decisions regarding the characteristics, cost, and availability of the data.

In the latter part of the decade, there are a number of land remote sensing instruments planned as part of NASA's EOS program, in cooperation with the European Space Agency, Canada, and Japan. Although the configuration and instrument payload of the NASA EOS spacecraft have not yet been finalized, it is possible to make some preliminary comparisons with Landsat. The EOS parameters for climate research, and therefore only four of the planned sensors—the Moderate-Resolution Infrared Spectrometer (MODIS), the Multi-Angle Imaging Spectro-Radiometer (MISR), the High-Resolution Imaging Spectrometer (HIRIS), and the Advanced Spaceborne Thermal Emission and Reflection (ASTER) Radiometer—will collect land-surface data in the visible and infrared portions of the spectrum. The highest spatial resolution capabilities of the MODIS and the MISR will be approximately 250 m, and so they are not directly comparable to Landsat.

The two EOS instruments that would have features similar to Landsat-6 are the HIRIS and the ASTER. Although the HIRIS is expected to have 192 spectral bands in the 0.4- to 2.45-micron wavelength region, the instrument would have a swath width of only 24 km and would be used for local area process studies, rather than for regional or global coverage. The narrow swath width would allow the HIRIS to view the entire Earth surface only every 138 days. Moreover, the HIRIS will not fly on the initial EOS spacecraft, and its development under that program is uncertain.

The ASTER instrument, which is being designed and built by Japan as a contribution to the NASA EOS program, would provide data most comparable to Landsat data. The ASTER is expected to have three visible and near-infrared bands at 15-m resolution, six shortwave infrared bands at 30-m resolution, and five thermal infrared bands at 90-m resolution. The swath width would be only 60 km, however, with a pointable cross-track range of 106 km. A significant difference for all of the EOS instruments may be in the spacecraft crossing time, which is currently planned for 1:30 p.m. The afternoon crossing time favors atmospheric and oceanic research objectives rather than the study of land-surface processes, which are better observed in the morning when there is statistically less cloud cover that might obscure the ground surface.

Thus, even if the follow-on to Landsat-6 were to contain no additional technical improvements, it would still provide a unique observational capability and continuity of this important data set well into a third decade. The committee must point out, however, that copying 1970's technology in the mid-1990s, even though serving a valuable data-collection function, will not take full advantage of current technological capabilities. Although the committee has not been able to review directly competitive technical options for improving the space segment of the Landsat system, it is aware of a number of proposed systems that may be able to provide more effective alternatives. The committee therefore recommends that the government, in considering alternative and innovative technologies for collecting a fully comparable data set into the next century, place the highest priority on maintaining uninterrupted continuity of the Landsat data set, even if that necessitates flying only a slightly improved version of Landsat-6.

IMPEDIMENTS TO EFFECTIVE UTILIZATION OF LANDSAT DATA

Despite the demonstrated success of Landsat technology and the well-documented importance of both the current and historical data to a host of applications, the committee has identified several factors that significantly inhibit more effective use of those data. These impediments may be divided into three categories: those associated with the perennial uncertainty about the long-term continuation of Landsat observations, those related to the cost of the data, and those concerning effective archiving of the data.

As noted in the committee's most recent report (*Assessment of Satellite Earth Observation Programs—1991*, Space Studies Board, 1991), uncertainty about the future continuation of the Landsat program began almost immediately upon its transfer from NOAA to the Earth Observation Satellite (EOSAT) Company in September 1985. Under the terms of the transfer, the government agreed to subsidize the operation of Landsat-4 and -5, as well as the procurement and launch of Landsat-6 and -7. For several years following the transfer, however, the budgets proposed by the Office of Management and Budget did not provide the funds to implement the transition plan. After much debate, the funding was restored each year by Congress. These funding uncertainties caused

delays and cost overruns in the development of Landsat-6 and postponed the development of Landsat-7. Potential end users consequently were unwilling to invest resources necessary either to learn how to use the data, or to develop the infrastructure to process the data. This uncertainty, unfortunately, still exists.

In 1990, at the request of Dr. D. Allan Bromley, assistant to the President for science and technology, the NRC undertook a special study to review the U.S. Global Change Research Program as described in the President's FY 1991 budget, and to address several specific questions about NASA's EOS program in the context of global change research. That report, *The U.S. Global Change Research Program—An Assessment of the FY 1991 Plans* (Committee on Global Change, National Academy Press, Washington, D.C., 1990), observed that:

> Current policies that govern the use, distribution, and cost of the Landsat and SPOT data make it difficult for the research community to take advantage of this resource. When purchased from the commercial remote sensing industry, the data are generally too expensive for most research purposes.

In testimony before the Senate Subcommittee on Science, Technology, and Space in October 1990, Dr. Lennard Fisk, Associate Administrator for the NASA Office of Space Science and Applications, estimated that it would cost over $50 million to purchase enough Landsat Thematic Mapper data to compose one "snapshot" of Earth.

Even if access to Landsat data were not significantly inhibited by cost, there would still be a problem in using many of the oldest data. According to a General Accounting Office report, *Environmental Data—Major Effort Is Needed to Improve NOAA's Data Management and Archiving* (GAO, Washington, D.C., November 1990), approximately half of the 130,000 Landsat tapes stored at the USGS EROS Data Center are over 10 years old and are deteriorating. The center does not have the hardware to read, process, and maintain over 30,000 tapes of Landsat-1, -2, and -3 data, and some have already deteriorated beyond recovery.

SUMMARY CONCLUSIONS AND RECOMMENDATIONS

The Landsat system has provided an invaluable environment information resource to our nation and the world. Landsat data have been used in a broad spectrum of basic and applied research. Even more significantly, however, the existing Landsat database and the system's anticipated observations are expected to play an increasingly important role in data-intensive endeavors such as global change research and Geographic Information Systems applications. Finally, there is no existing or planned remote sensing system that currently duplicates or can continue such observations in the event that the Landsat program is discontinued.

Not withstanding its notable successes and growing potential, the full capabilities of this unique data-collection system have been consistently underutilized and insufficiently supported, and the future continuity of the program remains in doubt. Although the committee has not analyzed the various options available for managing and operating the Landsat system in the future and makes no recommendations on those issues at this time, we wish to reiterate a number of recommendations made by this and other NRC committees that remain relevant to improving the effectiveness of the Landsat system for basic and applied research.

Program Continuity

As noted above, the committee places highest priority on maintaining uninterrupted continuity of the Landsat data set. Simply building and flying another spacecraft, however, is not enough to ensure continuity in the observations. First, a single spacecraft in orbit presents the possibility of a single-point failure and an interruption in observations. Most Earth observation spacecraft series that have been designated as "operational"—including the current Landsat series—maintain two spacecraft in orbit. This issue should be addressed in any decision to continue the program. Second, the sensors should be operated to obtain global land-surface data sets on a consistent basis. Third, all future sensors must be fully calibrated to enable long-term data intercomparability. Finally, the full value of land remote sensing will be realized only if there is continued research and development to create new sensors and if new generations of researchers are trained to use these data. This latter issue deserves greater attention and coordination among the agencies represented on the Committee on Earth and Environmental Sciences.

Access to Data

The effective utilization of Landsat data continues to be seriously compromised by their high cost. Although some progress has recently been made in this regard, notably the availability at the cost of reproduction of all Multispectral Scanner data that are at least two years old, the committee agrees with the 1990 NRC report (*The U.S. Global Change Research Program—An Assessment of FY 1991 Plans*) that:

> Landsat data are sufficiently important to global change research that means should be found to include them in the EOSDIS, whether by revising the Land Remote Sensing Commercialization Act, if necessary, or by paying (again) for the data.

Early inclusion of the Landsat data set in the EOSDIS would be especially useful for the prototype data analysis studies planned under the EOS program. The recommendation is consistent with the "Data Management for Global Change Research Policy Statements," officially released by the Office of Science and Technology Policy on July 2, 1991, which states:

> Data should be provided at the lowest possible cost to global change researchers in the interest of full and open access to data. This cost should, as a first principle, be no more than the marginal cost of filling a specific user request . . . .

The 1990 NRC report cited above also emphasized that:

> it is in the interest of international research to make all environmental data readily available to the global scientific community . . . . Similarly, U.S. scientists should have access to relevant data in foreign archives, and it is important that other nations be encouraged to establish similar data policy assessments.

This latter issue takes on increasing significance as the other nations with remote sensing capabilities are placing restrictions on data obtained in their environmental satellite programs. It is particularly important to note that many of the Landsat observations of areas outside North America—relevant to global change research—are received and archived by Landsat ground stations in other countries, and can only be obtained through them.

Maintenance of Historical Data

As the 1990 GAO report (*Environmental Data—Major Effort Is Needed to Improve NOAA's Data Management and Archiving*) pointed out, a significant fraction of the older Landsat data is rapidly deteriorating. Although the USGS has done an outstanding job overall in maintaining voluminous data sets and making them available to the research community, the restoration to the extent possible and proper maintenance of all the Landsat data, whether archived in the United States or abroad, should receive high-priority attention for future research use.

The committee believes that a renewed commitment by the government to the continuity of the Landsat program and to its effective applications will benefit the nation, and indeed the world. I would be pleased to discuss these issues with you further at your convenience.

Signed by
Byron D. Tapley
Chairman, Committee on Earth Studies

5
Congressional Testimony

5.1 Testimony on the Report of the Advisory Committee on the Future of the U.S. Space Program

Space Studies Board member Norman F. Ness delivered the following testimony before the Science, Space, and Technology Committee of the U.S. House of Representatives on January 29, 1991.

Mr. Chairman, members of the Committee, thank you for inviting the Space Studies Board to testify on the recently released Report of the Advisory Committee on the Future of the U.S. Space Program, chaired by Mr. Norman Augustine. Louis J. Lanzerotti, Chair of the Space Studies Board, is unable to be here because of a prior commitment. I am presenting this statement of the Board on his behalf. As many of you know, Dr. Lanzerotti served as a member of the Advisory Committee.

The Space Studies Board was established in 1958 by the National Academy of Sciences to provide guidance to NASA and other agencies concerned with civil space research. Over the years, the Board has prepared and released a large number of reports and research strategies intended to promote the success and vitality of the Nation's civil space program. The Board's recommendations are based on focused discussions among prominent researchers organized by discipline areas in the Board's standing committees and task groups. These committees and task groups have addressed, over the years, a broad sweep of space science and applications disciplines, including astronomy and astrophysics, space biology and medicine, microgravity research, solar and space physics, earth studies, and planetary and lunar exploration.

We have been asked today to provide our assessment of the Augustine Report and to comment on its implementation. The Report covers an immense territory of technical, programmatic, and institutional concerns; it was prepared by a committee of distinguished scientists, engineers, industry executives, and politicians, and is based on testimony by nearly 400 experts in space science, technology, and management. I will confine my remarks to a selection of topics that have been previously addressed by the Space Studies Board and by related special study groups convened by the Academy in recent years. Today's remarks will be related to (1) the priority of space research in the civil space program; (2) the role of a manned space station; (3) supporting theoretical and laboratory work and university participation; and (4) launch systems. The full implications of the Augustine Committee's Report are currently being evaluated by the Board, and will be the subject of additional discussion at our next meeting at the end of February. As I present the views of the Board, I will indicate a few areas that we expect to study further.

SPACE SCIENCE: PRIMARY GOAL OF THE CIVIL SPACE PROGRAM

The first concern noted in the Augustine Report is the deleterious effect of a lack of consensus in the civil space program. The National Research Council shares this concern, and clearly expressed the importance of shared national space goals in recommendations prepared for then President-elect Bush in 1988 *(Toward a New Era in Space)*. The Board supports the Augustine Committee's statement of broad goals, and especially its assignment of top priority to space science. In its report, *Space Science in the 21st Century*, the Board proposed that the advance of science and its applications be assigned at least equal importance in America's space program as any other goal, such as the capability of expanding man's presence into space. The *21st Century* report recommends that other related activities, such as the development of space technology, should be carried out so as to maximize scientific return, and states the view that beneficial applications of space technology are most likely to flourish if science is made the principal object of the civilian space program.

Giving space research top priority in the civil space program has the important ramification that its financial support must be assured. To address this concern, the Augustine Committee's Recommendation #1 provides that space science should be assured a fixed minimum percentage of NASA's total budget to ensure stable funding. This is fully consistent with the NRC's recommendation in *Toward a New Era in Space* that a space science program be configured with a *base* program of balanced investigation, with major new enterprises funded separately as *special initiatives*. Two major issues arising from this overall approach are the prioritization of research objectives within the base program, and whether or not the nominal 20% portion recommended by the Augustine Committee is enough to adequately support space science as civil space's number one priority. A related topic is the important one of ensuring the most efficient use of these resources, as urged in the Committee's report. The Board is studying these questions now.

ROLE OF A MANNED SPACE STATION

I would like to turn now to a second area of vital importance to the space research community: the role of a manned space station in space research. While the Augustine Committee concluded that microgravity research could benefit from human presence in space, it also stated that only a long-term program in life sciences could fully justify the construction of a space station. The scientific utility of a space station has been a concern of the Space Studies Board since 1983. In a statement to the NASA Administrator that year, the Board questioned the scientific need for a manned station before the beginning of the next (21st) century, while acknowledging a "special relationship" between the proposed station and space biological and medical research. In its report *Toward a New Era in Space*, the NRC recommended a shift away from microgravity research and "space manufacturing" and toward space biology and medicine as drivers for the space station program. This is fully consistent with the Augustine Report's conclusions. In our Board's report, A *Strategy for Space Biology and Medical Science for the 1980s and 1990s*, we appealed specifically for a station design emphasizing life sciences research. Based on this discipline's dual requirements for continuous access and manned intervention, the Board recommended that there be a dedicated Life Sciences Laboratory on the Space Station, and that a variable force centrifuge of the largest possible dimensions be designed, built and included in the initial operating configuration of this Life Sciences Laboratory.

While Space Station Freedom's design remains in a state of flux at the present time, existing proposed configurations appear to diverge from these recommendations. The Board plans to assess the results of the congressionally mandated 90-day redesign once the results of this activity are available. The usability of the redesigned station for microgravity research between Orbiter visits during the station's man-tended phase is another topic we will be discussing.

RESEARCH AND ANALYSIS AND THE UNIVERSITIES

Mr. Chairman, the third area I wish to discuss today is the very important one of the status of research and analysis (R&A) funding and the role of the universities in our civil space effort. The Augustine Committee expressed the view that R&A programs, along with several other supporting programs, should be assigned the same importance as flight hardware programs themselves. On the same page, the Augustine Report urges that universities and other non-NASA Center organizations be tapped increasingly as "primes" for space research. The

Board concurs strongly in these recommendations. The Board's *21st Century* study focused on major space undertakings, but asserts that, if these undertakings are to succeed, they must be built on a solid foundation of supporting research and technology, and on small-scale exploratory projects such as the Explorer and suborbital (rocket- and balloon-borne) programs. Supporting research must include stable funding for vigorous theoretical and laboratory studies, which provide the framework for understanding data obtained from scientific missions. The Board's research strategy for exploration of the outer planets, for example, contends that proper support of laboratory and theoretical studies is an integral part of any program of planetary exploration. This support must be sufficiently stable to maintain these activities at a professional level and to encourage participation of young investigators.

LAUNCH SYSTEMS

Mr. Chairman, my final topic for today is launch systems. The Augustine Committee recommends deferral of a fifth Orbiter, and supports an immediate start of development of an "unmanned, but man-rateable," heavy lift launch vehicle. While the NRC's recently published report, *Human Exploration of Space: A Review of NASA's 90-Day Study and Alternatives,* clearly supports the development of a modern launch system with heavy lift capability, the Space Studies Board has tended to be more concerned with assured access to space on vehicles appropriate to each research mission. If space research is to have the top priority within the future civil space program, it must influence the development of infrastructure, particularly space transportation. The Board believes that launch systems, delivery mechanisms, space platforms, and other such developments should never be looked upon as ends in themselves. Rather they should be treated as tools to support well-defined objectives. Where space research is concerned, the key desiderata for advanced launch systems are reliability (because payloads are costly to lose), a capacity for rapid processing (to ensure the timeliness of launches), low cost (allowing access to space for a wider community of users), and diversity and redundancy (so that failure of one element of the launch infrastructure does not shut down the nation's entire launch capability). These space science community concerns should be fully considered in launch system development planning.

In closing my statement, I would like to emphasize that omission from these remarks of the Mission to Planet Earth and the Mission from Planet Earth should not suggest that the Board attaches low importance to them. On the contrary, we are now completing two reports in the earth studies area, one an assessment of the state of the discipline, and the other an assessment of the Earth Observing System program. Our Committee on Human Exploration is initiating a broad study of the role of science investigations in a future manned exploration program. The Board looks forward to the opportunity to share the results of these important activities with you at a future date.

Thank you. I'll be happy to answer any questions you might have.

5.2 Testimony on the Space Station Freedom Program

Space Studies Board Chair Louis J. Lanzerotti delivered the following testimony before the Subcommittee on Science, Technology, and Space of the U.S. Senate, on April 16, 1991.

Thank you for inviting me to testify on behalf of the Space Studies Board regarding Space Station Freedom. As you know, the Board recently sent a letter and an accompanying statement to Admiral Truly regarding this space endeavor.[1] (See attached.) Since that time, a series of accounts have appeared in the press which have interpreted our statement with varying degrees of accuracy as to both the Board's intent in issuing the statement as well as to its contents.

Since the Board's statement was released, we have met with a number of congressional and administration officials as well as with NASA's Administrator Admiral Truly and other senior NASA personnel regarding the issues and concerns raised in our statement. I am happy to report that these discussions have been very constructive and valuable for all individuals involved. The Board and NASA have agreed to continue this dialogue in a positive and open fashion in order to better define the objectives of a space station as a national objective, including its role in Mission from Planet Earth (MFPE).

The beginning of this dialogue occurred at a meeting on April 8, when several members of the Board and of the Committee on Space Biology and Medicine met with Bill Lenoir, Associate Administrator for Space Flight, Dick Kohrs, Director of Space Station Freedom, Len Fisk, Associate Administrator for Space Science and Applications, Bob Rhome, Director of Microgravity Sciences and Applications, and Arnauld Nicogossian, Director of Life Sciences. We hope this was just the first of an ongoing exchange between NASA and the Board on issues associated with the national goals of SSF. The first purpose of the meeting was to discuss in a broader forum issues raised in the Board's March statement and to apprise the Board and Committee members of relevant decisions and changes that have occurred since early March related to the proposed station. The most significant of these was a commitment in the week preceding our discussion on April 8, to providing an on-board 2.5-meter centrifuge in the first assembly flight following Permanently Manned Capability (PMC)—now scheduled for FY 2000. The purpose of the centrifuge is to support research associated with the national goal of MFPE as outlined in Attachment 1 of the Board statement and will be discussed below.

With the exception of the centrifuge commitment, both sides discerned some continuing disagreement as to the best way to achieve research return from the Station essential to supporting a long-term human space exploration as well as some uncertainties about the resources that will be available. These concerns, described in the Board's March statement, will be discussed in the following sections on life sciences and microgravity research. I note that the time available to us on April 8 was insufficient for us to clarify all of the space biology issues; we had no time to address any matters related to "microgravity" research.

BACKGROUND OF SPACE STUDIES BOARD POSITION ON A SPACE STATION

Before I proceed with a summary of the Board's present views on requirements and issues associated with a space station program related to MFPE, I would like to take this opportunity to state clearly for the record that the Space Studies Board is not now, and has never in the past, been opposed to the concept of a space station or the national political goal of long-duration human spaceflight. There have been frequent references to a 1983 position of the Board on the scientific value of a space station.[2] That statement, written in response to a request from NASA, assessed the possible utility of a space station to accomplishment of the major scientific objectives of all of the disciplines of space research (except microgravity[3]) and concluded that most of these goals could be met using other means, with the exception of those activities lying within the realm of space biology and human adaptability and survival in spaceflight. Concerning this latter research area, the Board unequivocally stated that,

> A commitment by the nation to long duration human space flight, whether in Earth orbit or beyond, calls for the establishment of a facility for space biological and medical research on the effects on individuals of very long exposure to the "low g" environment. In this sense, the relationship of the life sciences to a space station is a special one.

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[1] *Space Studies Board Position on Proposed Redesign of Space Station Freedom*, March 14, 1991.

[2] *Space Science Board Assessment of the Scientific Value of a Space Station and Space Science in a Space Station Era*, September 9, 1983.

[3] The Board did not assume advisory responsibility for microgravity research until 1988.

In 1987, the Board's Committee on Space Biology and Medicine completed and published a major research advisory strategy in which the availability of a space station was described as pivotal.[4] This strategy was developed, written and reviewed within the NRC in the same manner as all of the Board's space research strategies, which have formed the basis for the vigorous national U.S. programs in such fields as space astronomy and planetary exploration.

Also in 1987, L. Dennis Smith, Chairman of the Board's Committee on Space Biology and Medicine, testified before the Senate HUD Appropriations Committee on the 1987 research strategy and issues associated with a space station.

> It is not an understatement for me to say that the strategy for space biology and medical research that we have recommended presumes the availability of a space station. While there are any number of experiments that can and should be conducted on the ground, their results only become meaningful when compared with those obtained in space.[5]

Last year, in testimony before the U.S. Senate Subcommittee on Science, Technology, and Space, the Board discussed space station utilization issues associated with microgravity and life sciences research. With respect to implementing the recommendations made in the space biology and medicine research strategy, the Board said,

> Two pivotal aspects of this strategy are recommendations that there be a dedicated Life Sciences Laboratory on the space station and that space biology and medicine be conducted as focused missions on the station. . . . In making these recommendations, the Committee and the Board concluded that they are critical to the successful implementation of the rationale on which the research strategy is based.[6]

I cite these examples of the Board's comments on a space station to illustrate that, contrary to some current accounts, the Board has never taken a position "against" a space station either in the past or in its recent statement. To the contrary, in the March statement, the Board declared, "The Space Studies Board strongly endorses the position that a space-based laboratory is required to study the physiological consequences of long-term spaceflight."

SPACE STUDIES BOARD MARCH 1991 POSITION ON SPACE STATION FREEDOM UTILIZATION

The following is a summary of the major issues and conclusions from the Board's March 1991 statement and a general description of the nature of life sciences and microgravity research. The Board's statement is restricted to an assessment of the Station's role in fulfilling the national goals for long-duration human spaceflight. The Board has also commented on the proposed use of the station for microgravity research. In these two cases, the conclusion that was reached is that,

> In the judgment of the Board, Space Station Freedom, at the present stage of redesign, does not meet the basic research requirements of the two principal scientific disciplines for which it is intended: (1) life sciences research necessary to support the national objective of long-term human exploration of space and (2) microgravity research and applications.

As I continue to note, the Space Studies Board recognizes that there are national imperatives for building a space station other than purely scientific research—a conclusion that was articulated by Vice President Quayle in his letter authorizing NASA to go forward with the proposed "new concept design for Space Station Freedom, . . . to the Congress."[7] In his letter to Admiral Truly, the Vice President noted, "It is vital, therefore, that the Space Station be considered an essential part of the larger Mission from Planet Earth. That mission includes the development of new infrastructures and the pursuit of new initiatives aimed at gaining scientific knowledge and establishing a permanent presence in space. This is the next vital step in the historic space mission America began over thirty years ago." With this articulated as a national goal, the Board emphasizes that the conducting of life sciences research on a space station is not a purely scientific pursuit, but rather a, if not the, critical factor in

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[4] *A Strategy for Space Biology and Medical Science for the 1980s and 1990s* (NAP, Washington, D.C., 1987).

[5] Testimony by L. Dennis Smith, Chairman, Committee on Space Biology and Medicine, Space Science Board to the Subcommittee on HUD and Independent Agencies Appropriations, U.S. Senate, May 1, 1987.

[6] Testimony by John A. Dutton for Louis J. Lanzerotti, SSB Chairman, to the Senate Commerce Subcommittee on Science, Technology, and Space, May 10, 1990.

[7] Letter from Vice President Danforth Quayle to Admiral Richard Truly, NASA Administrator, March 19, 1991.

determining the feasibility of the Vice President's vision of long-duration human space exploration. This is also the conclusion arrived at by the Advisory Committee on the Future of the U.S. Space Program.[8]

Space Biology and Medicine Research

The Augustine Committee concluded that the primary objective of a space station should be life sciences research in order to ascertain the feasibility of long-duration human spaceflight. The Board endorses this position. A space-based laboratory is required to study the physiological consequences of long-term space flight. This research is critical to enabling the nation's Space Exploration Initiative.

Nature of the Research

Space biology and medicine constitute only a small segment of the broad reach of biomedical and biological research conducted in the U.S. today. In contrast to other research fields such as astronomy, space physics, or earth remote sensing, the broader life sciences research community does not depend on space as a laboratory or working environment. While there are scientifically interesting life sciences experiments of a basic research nature in, for example, developmental biology and plant science, that could be conducted in a low-gravity environment, these experiments alone could not justify building a space station. The overwhelming research requirement for a space station is based on the need to perform the life sciences research necessary to support this country's goal of long-duration human spaceflight.

Space biology and medicine investigate how individual organisms and small groups of organisms respond to the microgravity of space and how they adapt. It has been clear for some time that when humans go into space, many changes occur in their physiology. Several studies have also indicated that basic biological processes are altered in microgravity. It is not likely that the two processes are separable. Human physiology is predicated on the homeostatic functioning of organs that are composed of cells. All of these complex functioning systems have evolved in the presence of gravity, and when exposed to microgravity, they are forced to function in a new and novel environment. To understand a biological organism's adaptation to microgravity, scientists are forced to evaluate not only the clinical manifestations of an organismal response to the new environment, but also the underlying cellular and organ response. This requires an integrated approach that includes both basic research as well as the more operational aspects of clinical research.

One strategy to understanding adaptation to microgravity involves empirical research in which humans or appropriate animal models are subjected to the space environment for prolonged periods and are continuously monitored for changes. This approach might lead to the development of countermeasures that would provide a quick "fix" for problems encountered, but it is not likely to elucidate the basic mechanism(s) behind the biological response to microgravity. A more appropriate research strategy is to study basic mechanisms, and based on the knowledge acquired, to design appropriate countermeasures. The only way to execute such a research strategy is in space, with the ability to control the most critical variable—gravity.

As described in the Committee on Space Biology and Medicine 1987 strategy report and a more recent assessment by the CSBM of the progress made in implementing advisory recommendations concerning life sciences research, moving forward with the Space Exploration Initiative will require not only the understanding and support of all of NASA, but the participation of other federal agencies as well.[9] Because of its central mission, which is, in turn, supported by a vast network of qualified specialists, the National Institutes of Health (NIH) offers tremendous potential to contribute to space life sciences. The Board and the Committee on Space Biology and Medicine strongly encourages enhanced collaborative activities between NASA and the NIH in order to pursue the research required to establish the feasibility of long-duration human spaceflight.

Space Biology and Medicine Research Requirements

In addition to basic and operationally oriented experimentation in flight, there is also a need for coordinated ground-based investigations. In particular, issues in human behavior that may be critical for long-duration mis-

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[8] *Report of the Advisory Committee on the Future of the U.S. Space Program*, Superintendent of Documents (GPO), December 1990.

[9] *Assessment of Programs in Space Biology and Medicine—1991* (in press).

sions need to be explored in analog environments. The Board's March 1991 statement provided a summary of the fundamental requirements for conducting the necessary space biology and medicine research on a space station. The following reiterates and elaborates on those requirements. These requirements are described in detail in *A Strategy for Space Biology and Medical Science for the 1980's and 1990's* (NAP, Washington, D.C., 1987), hereafter referred to as the 1987 strategy report.

Dedicated Life Sciences Laboratory

The empirical nature of space biology and medicine research requires continuous access to space as well as the opportunity for manned intervention. Based on these key requirements, the strategy report recommended the following.

> Based on the dual requirements of continuous access and manned intervention, the committee recommends that there be a dedicated Life Sciences Laboratory (LSL) on the Space Station. . . . Scientists must work closely with designers and engineers at every stage in the development of the LSL and the equipment that is to be used within it. The laboratory must have the flexibility to be rapidly converted to accommodate the needs of different types of combinations of experiments. The existence of a dedicated LSL serving many different functions, requires that provision be made to insert, remove, or reconfigure equipment, racks, and dividing walls. (Page 186)

We note that an internal NASA Committee advising on research on a space station (Task Force on the Scientific Uses of a Space Station, 1985 and 1986) also stressed the need for a dedicated life sciences laboratory.

In the Board's March 1991 statement, a point is made concerning scientific return versus investment. Maximizing research return for the investment is the underlying rationale behind the recommendation for a dedicated Life Sciences Laboratory. Neither the Board nor the Committee on Space Biology and Medicine suggests that nothing of research value could be done on the proposed station, but rather that the limited amount of data that could be obtained that would improve our understanding of the human response to a low-gravity environment would be worth neither the time nor the money expended. We particularly note that many of the fundamental problems in life sciences research will require long periods of time for their pursuit and solution. The best and most efficient way to conduct this type of life sciences research is to maximize flexibility in a dedicated laboratory.

The need for a dedicated Life Sciences Laboratory was discussed at some length at the April 8, 1991, meeting between NASA and members of the Board and the Committee on Space Biology and Medicine. At this point in time, it appears that there continues to be some disagreement between the Board and the agency as to whether this is a desired accommodation or an essential research requirement.

Need for Focused Missions

Integrally linked to the recommendation for a dedicated Life Sciences Laboratory is the Committee on Space Biology and Medicine's recommendation for focused missions. Again, the purpose of this research recommendation is to increase efficiency and to maximize research return.

The field of space biology and medicine is far from a mature discipline. In the context of the Space Exploration Initiative, it will be necessary to make significant progress in understanding the effects of microgravity on living organisms. To this end, the CSBM's 1987 strategy recommended that

> . . . research time on the Space Station be divided into 3-6 month blocks, with each block largely devoted to a single research area. Missions in each subdiscipline should occur at least three times each decade. (Page 187)

The advantages to this approach include training of qualified specialists to conduct the experiments and simplification of mission planning and implementation because of common equipment and research subjects. The 1987 research strategy explained why this approach is desirable.

> The proposed mode of research resembles that which is carried out in the other space sciences. Each mission is devoted to a single, broadly conceived goal. Sufficient flight time is given to collect reliable results, to replicate experiments when necessary, and to change protocols as data are gathered and interpreted. If such a strategy is adopted, space biology and medicine can become a mature science within one to two decades. (Page 188)

Flexibility in Spaceflight Experiments

Providing for the flexibility needed to conduct life sciences research in terms of time, laboratory equipment, and research personnel makes it undesirable to plan for sharing a laboratory with other disciplines. The 1987 strategy report describes ways in which experimental flexibility can be enhanced:

> The first requirement is rapid feedback of results during the mission. This, in turn, implies an increase in on-board analytical capabilities and the ability to communicate the results in an understandable manner to both the crew doing the experiment and their ground-based colleagues. Second, it is important that the two groups be able to exchange data, information, and ideas. Third, there has to be flexibility in the availability of equipment and experimental organisms, as well as in the scheduling of experiments. (Page 193)

General Facilities

It is important to emphasize that much, if not all, of the equipment and support facilities such as refrigerators, freezers, growth chambers, incubators, and a centrifuge required for life sciences research must remain in operation at all times. Therefore, there must be sufficient power to support both this equipment and additional specialized apparatus associated with the conduct of specific experiments.

There was some discussion concerning facilities and equipment at the April 8 meeting. Following these discussions, the Board continues to remain somewhat concerned and uncertain as to exactly what equipment and resources will be available for research. While we have been assured that there will be "sufficient power" for users, we have not been given specific information as to what investigations are planned, or how the facilities requirements for space biology and medicine research are used to define the station's infrastructure. In fact, we have been advised by CSBM members who serve on various NASA space biology and medicine discipline working groups that the process of defining these investigations and experiments is at an early stage, thus making it difficult to assess specific power and facilities needs even as the station program moves forward.

Variable Force Centrifuge

For over twenty years, virtually every internal and external life sciences advisory group to NASA has emphasized the absolutely critical need for a centrifuge in space.[10] A variable force centrifuge (VFC) is the single most important facility for space biology and medicine research. It would serve three equally important functions. First, it would provide an on-board 1-g control that can separate the influence of weightlessness from the other effects encountered in spaceflight. Second, microgravity has both short-term and long-term effects on biological systems. Both kinds of effects involve important biological phenomena. Their study would be greatly facilitated by a VFC, which would allow exposure to microgravity or to simulated gravitational forces for varying periods of time. Third, the removal of gravitational forces is already known to have major impacts on biological systems. In such cases, it is of particular importance to determine if there is a threshold force required for a response to occur and, more generally, to ascertain the dose-response relationship. A centrifuge would provide the only way to answer these questions because it makes possible the introduction of fractional g-forces. Its inclusion should greatly increase the research return from space experiments. We note that the Office of Science and Technology Policy has also emphasized the need for a centrifuge on the station. In the 1987 strategy report, the committee stated,

> The VFC should be capable of supporting a wide variety of species and must run for several months without stopping. Specimens will have to be placed on the VFC or removed from it while it is spinning. We have been apprised of the engineering problems involved in the inclusion of a large centrifuge in a freely floating Station. The committee still recommends that a Variable Force Centrifuge of the largest possible dimensions be designed, built and included in the initial operating configuration of the Life Sciences Laboratory. It does so because a VFC is an essential instrument for the future of space biology and medicine. (Page 193)

[10] 1987 strategy report cited previously. Also, Committee on Space Biology and Medicine Letter to Andrew Stofan, Associate Administrator, Office of Space Station, July 21, 1987, and testimony by L. Dennis Smith to the Senate Subcommittee on HUD Appropriations, May 1, 1987.

As I have already indicated, we learned at the April 8 meeting that NASA has now committed to providing a 2.5-meter centrifuge on the station on the first assembly flight following PMC. This was a welcome piece of news.

Animal Holding Facilities and Plant Growth Chamber

The conduct of biological and medical research requires both human and animal subjects. As the number of available human subjects on the space station will always be limited, the Board cannot overemphasize the critical need for animals to be used in the required research. The station must provide for housing both small and large animals. The 1987 strategy report recommended that

> A Research Animals Holding Facility (RAHF) should be included in the initial operating configuration of the Life Sciences Laboratory. The RAHF should be modular and flexible and should accommodate both large and small animals. Advances in biology have often been based on the use of comparative methods, and space biology would benefit similarly from the availability of a wide range of animals. The individual units of the RAHF should be easily mated to the VFC and to other equipment. (Page 193)

At the April 8 meeting, NASA indicated that current plans call for housing research animals in the same facility that will contain the 2.5-meter centrifuge.

On-Board Handling and Analysis of Samples and Cell and Tissue Specimens

Cell and tissue specimens will require a variety of equipment for analytical biochemistry, automated radioimmunoassay, and radioactive tracer studies. With respect to humans, there must be a system for preservation and storage for blood, urine, and stool samples. The 1987 strategy report recommends that there be facilities

> . . . for the fixation and sectioning of specimens and a light microscope with direct and phase contrast optics. The microscope should have an attached video camera that interfaces with a computer-based image processor. A sterile tissue culture facility should include provisions for media preparation, a preparative centrifuge, incubators, 1-g rotating discs for control cultures, a glove box, and freezer and cooler units. Freezers are needed for sample and carcass storage. In addition, provision for rapid sample return to earth is desirable. (Page 193)

Computational Facilities

There should be some provision for rapid access to data both by the station crew and ground-based scientists as well as for rapid communication between the two groups. There should be dedicated microprocessors that can be used for both process control and data storage.

Research Personnel

Central to the conduct of biological research is a sufficiently large sample size on which to reliably base findings. The subject of choice for most of the research required is humans. There simply must be adequate numbers of humans in space who can serve as subjects. Just as important, there must be well-trained, skilled scientists who conduct the experiments. The 1987 strategy recommended that there be a minimum of two dedicated, appropriately trained scientists on each mission. On April 8, the Board began discussions with NASA related to the planned evolution in crew numbers. There was insufficient time on that day to fully explore the issue.

Cabin Atmosphere and Composition

In a recent letter report, the Board made recommendations about the space station's cabin atmosphere. The Board found that a 14.7 psi/21% oxygen atmosphere is much preferred for two principal reasons. First, the fire risk increases with an increasing fraction of oxygen, which would be the case with the originally proposed 10.2 psi/"normoxic" atmosphere. Second, the vast majority of the existing scientific database for biological and medical research is based on measurements made at or near sea-level conditions. Space research conducted under

other conditions could not be directly compared to this extensive existing body of knowledge. Similar advisory information was supplied by a NASA internal committee related to the space station.[11]

Based on these considerations, the Board recommended in a December 1990 letter report to NASA that the space station be operated at 14.7 psi/21% oxygen. If it is necessary to lower the pressure, the station should be designed to accommodate a range of pressures, and the station should be operated at 14.7 psi/21% oxygen whenever extravehicular activity (EVA) is not scheduled, including, during the man-tended phase, utilization flights and periods between shuttle flights. Further, the Board recommended that beginning with the permanently occupied phase, the pressure should be maintained at 14.7 psi/21% oxygen.[12]

Inadequacy of Space Station Freedom for Space Biology and Medicine Research Requirements in Support of Mission from Planet Earth

The Board's March 1991 statement concerning SSF described the reasons why the proposed station will be inadequate to support the biological and medical research that have been recommended.

1. Plans for the size and location of a centrifuge and of animal holding facilities are insufficiently defined for proper evaluation. As emphasized in the Board's 1987 strategy report, an adequate centrifuge is essential to provide a 1-g control for 0-g experiments and *also* to explore the adequacy of artificial gravity for long-duration spaceflight.
2. The plan to share limited power among multiple users in all laboratory modules threatens the reliable availability of sufficient power to conduct the volume of long-term biological experiments required to support a human space exploration initiative.
3. The proposed crew size is insufficient to conduct the requisite experiments in a reasonable time period.
4. The absence of a dedicated Life Sciences Laboratory will prohibit some experiments and will severely restrict most others, prolonging the acquisition of data required to answer fundamental questions related to the feasibility of long-duration human space exploration.

The principal change in the station program since the Board's statement was issued in March 1991 is NASA's announcement to us of a new commitment to a 2.5-meter centrifuge with accompanying animal holding facilities and equipment that will constitute a critically needed augmentation to the life sciences potential of the station. However, the Board has three concerns about the centrifuge proposal:

1. It will not be available for use until 2000 at the earliest. This implies that life sciences research, critical to planning for the Mission from Planet Earth, cannot be meaningfully started until that date. The time required to obtain and understand data acquired using this equipment will be added to the delay imposed by the delayed start of the research.
2. The centrifuge and associated equipment are not contained within the present funding plan worked out with Congress. Initiation of definition and procurement must be based on either new funding or on a funding "wedge" of available resources that might appear after the pace of development expenditures for the Permanently Manned Capability (PMC) capability begins to slacken in the mid-1990s. The Board is concerned about this approach to funding the centerpiece equipment elements for the primary science objective of the station.

In summary, our recent discussions with NASA have not revealed an evolutionary planning approach that ensures a research facility for providing data required to establish the feasibility of long-duration spaceflight.

Microgravity Research

Nature of the Research

Microgravity research is that research conducted in a gravitational field (or equivalent acceleration with respect to an inertial frame) that is a small fraction of the gravitational acceleration, g_E, of the earth.

[11] SESAC Task Force on Scientific Uses of a Space Station, *Space Station Summer Study Reports*, March 21, 1985, and March 1986.
[12] SSB letter to Joseph Alexander, Assistant Associate Administrator, NASA Office of Space Science and Applications, December 12, 1990.

Similar to the field of space biology and medicine, this is a field at its earliest stage of development and involves investigators from a widely diverse scientific community. To date, no examples have been found of materials that are worthy of manufacture in space. Unless and until such examples are found, space manufacturing should not be used as a rationale for this program. Rather, the rationale for research in a microgravity environment should be to improve our fundamental knowledge base, including those areas that might reasonably be expected to lead to improvements in processing and manufacturing on the earth. Furthermore, methodologies for carrying out this research should be determined by the research requirements and therefore the researchers, including the selection of the appropriate vehicle—force flyers, drop towers, extended duration Spacelabs, and so on.

Strictly speaking, the prefix "micro" would imply a gravitational field of 10^{-6} g_E, but we use the word "microgravity" in a more generic sense to describe gravitational fields that are typically less than 10^{-2} g_E but might even be lower than 10^{-6} g_E, or 9.3 g_E, respectively.

Gravity is a very weak force compared to the strong or weak nuclear forces that bind atomic nuclei or subnuclear particles, or to the electromagnetic forces that bind atoms and molecules. Therefore, the role of gravity in physical phenomena is only important whenever these stronger forces are already in balance, or whenever special circumstances arise.

Thus, gravitational effects can become decisive in a variety of cases. A first case is, as a driving force for convection in fluids. Differences in density, due to inhomogeneity in temperature and/or composition, can cause an otherwise quiescent fluid to convect, thus giving rise to non-diffusive heat and mass transport. A second case is as a driving force for phase separation. Once electromagnetic forces have led to coexisting phases, such phases can still have different densities, and phase separation can occur, even by sedimentation over long times, if the density difference is slight. Third, near a critical point there is such a delicate balance of forces that thermodynamic and transport phenomena can exhibit divergent or anomalous behavior. Thus, even the slight inhomogeneity in hydrostatic pressure that arises whenever matter is in a gravitational field can lead to important differences in observables. Fourth, in the presence of very weak binding forces, there may be cases, particularly in living systems, in which the forces that bind molecules or determine the behavior of complex macromolecules would be important. Examples might be the crystallization of a protein in the development of a cell or an embryo. The last case is in the presence of very large masses or for very long times. For example, there are relativistic phenomena in astrophysics such as the bending of starlight, and the production of gravitational waves. Finally, in structural members or over large distances, for example, the stresses in buildings or bridges or within the earth or its atmosphere.

Proposed Research

To date, most microgravity experiments that have been proposed or conducted address the first two areas. Examples of these experiments include crystal growth from fluids, fundamental phenomena in crystal growth, convection and combustion phenomena, fire safety aboard spacecraft, preparation of immiscible alloys, and containerless processing.

The third area, critical points, has identified two principal experiments—the Lambda Point Experiment and the Zeno Experiment. The Lambda Point Experiment is designed to obtain a sufficiently large volume of superfluid helium very near to the critical temperature in order to better test the theory of critical point exponents. The Zeno Experiment will measure the large density fluctuations in xenon near the critical point that are responsible for producing the phenomena of critical opalescence.

Experiments concerning weak binding forces are not yet readily identifiable. The growth of protein crystals could be affected by convection phenomena, or by more subtle direct gravitational forces that can distort macromolecules. Similarly, weak gravitational signals could influence the direction of growth of plants or the development of cells.

Relationship of Microgravity Research to a Space Station

The Committee on Microgravity Research has advised the Board that, unlike the field of space biology and medicine, only a limited amount of the desired research in microgravity, at least over the next decade, can best be accomplished with a space station. The use of crew-tended free flyers, drop towers, extended duration Spacelabs,

and so forth offer adequate—and, the committee states, in fact more viable—opportunities for the research needs in many cases. This advisory view is consistent with opinions expressed by the Office of Science and Technology Policy (OSTP).[13] "With regard to space station microgravity science, we conclude that (a) its commercial prospects are remote, (b) its value as fundamental science is not qualitatively superior to that of other research, and (c) its attractiveness depends on the space station being constructed for other purposes . . . this activity does not provide a significant rationale for the space station."

The Board's March 1991 Statement concerning microgravity research enumerated the critical requirements for conducting microgravity research, including that which might be considered for a space station.

1. Adequate power, research volume, and support space.
2. Skilled, on-board scientific personnel in sufficient numbers to carry out experiments and to diagnose and correct malfunctions.
3. Suitable acceleration environment and adequate monitoring.
4. Affordable de-integration and re-integration of experiments on orbit.
5. Capability to integrate advanced techniques and instrumentation as these become available.
6. Fast turnaround for specimens that must be characterized on the earth.

In the context of these requirements, the Board described why the proposed station would be inadequate and outlined what is not provided for:

1. A low, quiescent acceleration environment, unhampered by crew activities, docking maneuvers, and other system activities necessary to sustain a permanently occupied presence.
2. A crew that would spend sufficient time working with the equipment.
3. Sufficient power, data-handling capabilities, and research volume.
4. The flexibility to upgrade systems; this deficiency is especially disconcerting in the area of computers, in which obsolescence is extremely rapid.

During the April 8 meeting, and again during hearings before the cognizant House Appropriations Subcommittee on April 9, NASA stated that three utilization flights would be provided for station microgravity utilization during the crew-tended phase. NASA gave assurances that these flights would be entirely free of assembly or maintenance activities that could interfere with microgravity research in progress. While these circumstances could, in principle, allow use of the crew-tended station for some types of microgravity experimentation, the Board remains concerned about the availability of suitable experimental equipment in the 1997 time frame. In particular, adaptation of Spacelab equipment for near-term use on the station would be more costly than continuing to use it on Spacelab.

The Board has been apprised of plans to use the crew-tended station for more sensitive experiments between shuttle visits. Such research would require highly automated equipment. In 1989, the NRC performed an assessment of a Commercially Developed Space Facility, a less capable system, but one that is in many ways analogous to the crew-tended configuration of Space Station Freedom.[14] This assessment expressed reservations about operation of Spacelab-derived equipment on an unattended spacecraft:

> The present generation of microgravity experiments is largely designed to be tended by humans, and approximately 40 percent of experiments to date have required unscheduled human intervention.

Overall, the Board continues to support its March 1991 statement on microgravity research, that, "In the judgment of the Board, the limited microgravity research that could be conducted on the redesigned space station as currently proposed does not merit the investment. If such funds were made available, the research community would likely choose to spend them in a very different way. The Board believes specifically that more research progress could be achieved in a shorter period of time and at a fraction of the cost through an expanded program of Spacelab missions and of free-flyer experiments."

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[13] *Scientific Rationale for the Restructured Space Station*, Office of Science and Technology Policy, March 11, 1991.

[14] *Report of the Committee on Commercially Developed Space Facility* (NAP 1989), page 3.

CONCLUSION

The Space Studies Board is the National Research Council's primary advisory body concerning the U.S. civil space research program. It is the Board's responsibility to provide timely and objective advice both when requested by NASA or when, in the view of the Board and the NRC, it is warranted and appropriate to do so.

Space Station Freedom offers the potential of serving as a major national resource for years to come. If the station is to fulfill its potential as a research base for establishing the feasibility of long-duration human space flight, then the scientific research community must play a central role in establishing the research requirements for space biology and medicine. It is necessary to continue to seek ways to obtain the advice and thinking of the most talented individuals on the research issues involved with this national political objective. The shared goal, if the station is a national objective, of a well-planned, highly productive and unique laboratory in space must motivate all parties concerned—decision makers, industry, NASA, and the scientific community—to work together to define, design, and operate the best possible space station that there can be.

5.3 Summary Testimony on the Space Station Freedom Program

Space Studies Board Chair Louis J. Lanzerotti provided the following summary testimony to the Subcommittee on Government Activities and Transportation of the Committee on Government Operations of the U.S. House of Representatives on May 1, 1991.

Thank you for inviting me to present the views of the Space Studies Board.

The Space Studies Board was established in 1958 as the National Academy of Sciences' primary advisory body to the U.S. civil space research program. It is the Board's responsibility to provide timely and objective advice when requested by NASA or when, in the view of the Board and the NRC, it is warranted and appropriate to do so. Over the years, the Board has prepared and released a large number of reports and research strategies intended to promote the success and vitality of the Nation's civil space program. The Board's recommendations are based on focused discussions among prominent researchers organized by discipline areas in the Board's standing committees and task groups. These committees and task groups have addressed, over the years, a broad sweep of space science and applications disciplines, including astronomy and astrophysics, space biology and medicine, microgravity research, solar and space physics, earth studies, and planetary and lunar exploration.

As you know, the Board recently released a statement concerning the scientific utilization of Space Station Freedom. This statement has been widely discussed, and occasionally misinterpreted, both in terms of the statement's contents and Board's intent in issuing it. In the course of my remarks, I hope to clarify some of these misunderstandings.

Since the statement's release we have met with a number of congressional and administration officials as well as with Admiral Truly and other senior officials from NASA. The most recent of these meetings was on April 8, when a number of Board members and members of our Space Biology and Medicine Committee met with key NASA managers in the Offices of Space Flight and of Space Science and Applications. Discussion at this meeting focused on space biology and medicine issues related to Space Station Freedom. We have agreed that this meeting was just the first of what will be an ongoing exchange between NASA and the Board.

BACKGROUND OF SPACE STUDIES BOARD POSITION ON A SPACE STATION

Before I proceed with a discussion of the Board's present view on requirements and issues associated with the space station program, I would like to take this opportunity to state clearly for the record that the Space Studies Board is not now and has never in the past been opposed to the concept of a space station or to a national political goal of long-duration human spaceflight. There have been frequent references to a 1983 position of the Board on the scientific value of a space station. That statement, written in response to a request from NASA, assessed the possible utility of a space station to the accomplishment of the major scientific objectives of space research disciplines (except microgravity) and concluded that *most* of these goals could be met using other means, with the *exception* of space biology and human adaptability and survival in long-duration spaceflight. The Board has testified to Congress on these matters on several occasions. In addition, the Board published a research strategy for space biology and medicine in 1987, in which the requirement for a space station by these disciplines was described as *pivotal*, if the Nation is to pursue a program of human exploration.

I cite these examples of the Board's comments on a space station to illustrate that, contrary to some current accounts, the Board has never taken a position "against" a space station either in the past or in its recent statement. On the contrary, in the March statement, we declared, "The Space Studies Board strongly endorses the position that a space-based laboratory is required to study the physiological consequences of long-term spaceflight."

SPACE STUDIES BOARD MARCH 1991 POSITION ON THE RESTRUCTURED SSF

Now I would like to turn to a summary of the major issues and concerns raised in the Board's March 1991 statement on the space station. As I continue to note, the Space Studies Board recognizes that there are national imperatives for building a space station other than pure scientific research. This, I might add, is consistent with a

view articulated by Vice President Quayle in a letter to Admiral Truly authorizing NASA to go forward with the proposed concept design for Space Station Freedom. I would like to emphasize that the Board confined its March assessment to the Station's roles in preparing for future long-duration spaceflight and in supporting microgravity research. The Board concluded that, "at the present stage of redesign, [Space Station Freedom] does not meet the basic research requirements of the two principal scientific disciplines for which it is intended: (1) life sciences research necessary to support the national objective of long-term human exploration of space and (2) microgravity research and applications."

In the context of the national goal of Mission from Planet Earth, the Board emphasizes that the driving force for life sciences research is not based on abstract scientific merit, but rather on its critical role in determining the *feasibility* of the Administration's vision of long-duration human space exploration.

Space Biology and Medicine Research

The conclusion of the report of the Advisory Committee on the Future of the U.S. Space Program, chaired by Mr. Norman Augustine, is that life sciences research necessary to support this country's goal of long-duration human spaceflight is the principal justification for the space station, a conclusion with which the Board's statement fully concurs. While there are scientifically interesting life sciences experiments that could be conducted in a low-gravity environment, these experiments alone could not justify building a space station.

The study of space biology and medicine requires an integrated approach that includes both basic research as well as the more operational aspects of clinical research. We particularly note that many of the fundamental problems in space life sciences will require long periods of time for their pursuit and solution. The only way to execute such a research strategy is in space, with the ability to control the most critical variable—gravity. Therefore, progress in these areas requires a suitably equipped, long-term, manned space laboratory—a space station.

There are a number of absolutely critical requirements that a space station must meet to support an effective and efficient program of space biology and medicine research. These are described in detail in my written testimony as well as in the 1987 research strategy published by the Board. Briefly, they include:

1. *A Dedicated Life Sciences Laboratory*—to provide the continuous access and human intervention needed for biological research;
2. *Focused Missions*—to allow sufficient flight time to collect reliable results, to replicate experiments when necessary, and to change protocols as data are gathered and interpreted;
3. *Flexibility*—to permit manipulation of equipment, experimental organisms and scheduling of experiments;
4. *Variable Force Centrifuge*—to provide an onboard 1-g control for experiments,to permit on-and-off acceleration for gauging time evolution of microgravity effects, and to investigate partial gravity countermeasures;
5. *Supporting Facilities*—research animal holding facilities and a plant growth chamber, computing facilities, supporting analytical equipment for handling and analysis of cell and tissue specimens, and a system for preservation and storage for blood, urine, and stool samples;
6. *Research Personnel*—a sufficient number of skilled scientists in appropriate disciplines to plan and perform necessary experiments, and to respond effectively to problems or unanticipated findings and opportunities;
7. *Research Animals*—to serve as subjects for microgravity adaptation and countermeasures experiments.

The design and planning for a station that is to support a national goal of long-duration human space exploration *must* be responsive to these fundamental research requirements.

Inadequacy of Restructured SSF for Space Biology and Medicine Research in Support of MFPE

Since the release of the Board's March statement, NASA has informed us on 8 April that they are now committed to providing a 2.5-meter centrifuge on the first space station assembly flight following PMC. This was a welcome announcement because of the centrifuge's absolutely critical role in conducting meaningful research. It is important to note for the record, however, that under this plan, research critical to planning for Mission from Planet Earth cannot be *started* until after 2000, when the centrifuge becomes available. In recent testimony before the Senate, NASA's Associate Administrator for Space Science and Applications, Dr. Lennard Fisk, stated that, even in an optimistic scenario, fully validated life sciences results bearing on long-duration spaceflight would not become available until 2007. Further, the centrifuge and supporting facilities will require a significant infusion of

new funds which are not identified in the existing budget agreement for the station. This is an important inconsistency between the accepted principal mission of the space station and its present planning and funding approach.

Aside from the centrifuge, the other concerns raised by the Board in its March statement still remain—inadequately defined power requirements and availability, an insufficient number of crew to conduct experiments and to serve as subjects, the absence of a dedicated laboratory, and no plans for focused missions. NASA and the Board have agreed to continue discussing these matters.

Microgravity Research

As is true with space biology and medicine, the field of microgravity research is at a very immature stage. To date *no* examples have been found of materials that are worthy of manufacture in space. Unless and until such examples are found, space manufacturing should not be used as a rationale for this program. Rather, the research rationale should be to improve our fundamental knowledge, particularly in those areas that might reasonably be expected to lead to improvements in processing and manufacturing on earth. Furthermore, methodologies for carrying out this research should be determined by the research requirements, including the selection of the appropriate vehicle—free flyers, drop towers, extended duration Spacelabs, etc. The Board and its Committee on Microgravity Research concluded that only a limited amount of the desired research in microgravity, at least over the next decade, can best be accomplished with a space station. In most cases, other vehicles offer more viable opportunities and lower costs.

Inadequacy of Restructured SSF in Support of Microgravity Research

NASA has stated that three utilization flights per year during the station's assembly period will be devoted to microgravity research. While these circumstances could, in principle, allow use of the crew-tended station for some types of microgravity experimentation, the Board remains concerned about the availability of suitable experimental equipment in the 1997 timeframe. Apart from the cost of the station itself, adaptation of Spacelab equipment for near-term use on the man-tended station would be more costly than continuing to use it on Spacelab. During the unattended periods, on the other hand, research would require highly automated experimental equipment. It would be difficult to adapt existing Spacelab experiments for teleoperation, and microgravity research conducted to date has required substantial unscheduled human intervention.

CONCLUSION

While Space Station Freedom, if built according to the present restructured plan, is potentially capable, over the long term, of contributing to space biology and medicine, serious issues remain with respect to its timeliness, cost-effectiveness, and evolutionary planning for establishing the feasibility of a long-duration human space exploration. If the space station is to fulfill its potential for supporting this essential space life sciences research, its design and operation must be highly responsive to life sciences requirements, The members of the Space Studies Board and its committees are committed to working with NASA and the national space policy community to help bring about the most productive, cost-effective, and exciting space program that the taxpayers' investment can deliver.

5.4 Testimony on the NASA Fiscal Year 1992 Budget Proposal (House)

Space Studies Board Chair Louis J. Lanzerotti delivered the following testimony before the Subcommittee on VA, HUD, and Independent Agencies of the Committee on Appropriations of the U.S. House of Representatives on May 2, 1991.

Mr. Chairman, members of the Subcommittee, thank you for inviting the Space Studies Board to testify on NASA's FY92 budget proposal. The Board was briefed by NASA officials on the budget during our meeting in late February; our testimony today is based on ensuing Board discussion on these and other matters related to the U.S. civil space program.

The Space Studies Board was established in 1958 by the National Academy of Sciences to provide guidance to NASA and other agencies concerned with civil space research. Over the years, the Board has prepared and released numerous reports and research strategies intended to promote the success and vitality of the U.S. civil space program. Board recommendations are based on focused discussions among the prominent researchers who constitute its standing committees and task groups. These committees and task groups have addressed, over the years, a broad sweep of space science and applications disciplines, including astronomy and astrophysics, space biology and medicine, microgravity research, solar and space physics, earth studies, and planetary and lunar exploration.

Mr. Chairman, I would like to divide my remarks today into three general parts: the first is an assessment of the overall funding proposal for NASA relative to the recommendations of the Advisory Committee on the Future of the U.S. Space Program[1] (the "Augustine Committee"); the second includes several consensus views on narrower topics from our February Board meeting; and the third concerns the restructured space station.

GENERAL ASSESSMENT OF THE PROPOSED NASA FY92 BUDGET

Before remarking on NASA's FY92 budget proposal, I would like to remind those present that I was a member of the Augustine Committee. Having said this, I would also like to state that the Space Studies Board concurs broadly with many of that committee's recommendations. The Augustine Committee recommended a near-term real dollar increase of 10% per year for NASA, a figure closely approximated by the currently proposed budget increase of 14%, once inflation is taken into account.

Beyond endorsing the proposed aggregate budget increase, the Board is solidly supportive of the primary importance assigned by the Augustine Committee's report to the role of space science as the "fulcrum" of our civil space program. Although there has been some discussion within the Board as to whether the present fraction of the total budget adequately reflects the primacy of this role, the Board strongly endorses the principle of the statement.

The recommendation that the Mission to Planet Earth (MTPE) and the Mission from Planet Earth (MFPE) be undertaken in that priority order was also sympathetically received by the Board. I would like to call attention, however, to an important related suggestion made in the Augustine Committee's report:

> The large size, broad scope and national importance of the U.S. Global Change Research Program also suggest that the EOS funding be provided as a line item, separate from other science programs.[2]

The Board is concerned that if MTPE programs are not isolated from core elements of the Office of Space Science and Applications (OSSA) program, the long duration and vast scope of the EOS and precursor missions, taken together, could seriously impact the resources available to these core research programs.

HUBBLE REPAIR, SPACE ROBOTICS TECHNOLOGY, AND RESEARCH AND ANALYSIS FUNDING

Having expressed the Board's overall satisfaction with the proposed growth in NASA funding, I would like to turn now to several concerns that emerged during the Board's discussions at our meeting in February.

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[1] *Report of the Advisory Committee on the Future of the U.S. Space Program*, Superintendent of Documents (GPO), December 1990.
[2] Reference 1, p. 27.

Hubble Repair

First, decisions will soon be made on the technical approach for correcting the optical deficiencies of the Hubble Space Telescope. The Board believes that evaluation of the Corrective Optics Space Telescope Axial Replacement (COSTAR) repair option, and any decision on its implementation, should consider not only its cost, schedule, and engineering feasibility, but also trade-offs with, and impacts on, second-generation Hubble instruments. The costs of Hubble repairs and upgrades subsequently undertaken should be closely monitored and controlled to minimize effects on other OSSA programs.

Space Robotics Technology

Second, advances in robotics capability are essential to NASA's space science and applications programs. The value of robotics to the unmanned exploration program has significant demonstrated benefits to scientific research, irrespective of the status or existence of a human exploration program. The Board is concerned about the deletion of robotic exploration technology funding for planetary rover, sample acquisition, and autonomous rendezvous, docking, and landing. The Board recommends that support for these efforts be restored, and, if possible, augmented.

Research and Analysis

Third, the Board reaffirms its position that vigorous research and analysis (R&A) and suborbital research programs are essential to the overall vitality of the national space research agenda.[3] The Augustine Committee also emphasized the importance of these programs.[4] NASA should take steps to ensure healthy growth in these budgets and to protect them from encroachment by troubled major flight projects. In particular, the Board strongly supports the proposed targeted increases in life sciences and planetary exploration R&A.

THE RESTRUCTURED SPACE STATION

As you know, the Board recently released a statement expressing serious reservations about the science capabilities of the restructured space station design.[5] This statement has unfortunately been misinterpreted in some quarters. I would like to take this opportunity to state clearly, for the record, that the Space Studies Board is not now, and has never been in the past, opposed to the concept of a space station or to a national goal of long-duration human spaceflight. A 1983 position of the Board on the scientific value of a space station, written in response to a request from NASA, assessed the possible utility of a space station for accomplishment of the major scientific objectives of all space research disciplines (except microgravity research). The Board concluded that *most* of these goals could be met using other means, with the *exception* of space biology and research on human adaptation and survival in long-duration spaceflight. The Board published a research strategy for space biology and medicine in 1987[6] in which the requirement for a space station for this discipline was described as *pivotal*. The Board has also testified before Congress on science requirements for a space station on several occasions. In May 1990, the Board expressed " . . . continuing concern about the utility of the space station as now planned, for microgravity, life sciences, and for the research necessary [to support] long duration spaceflight."[7]

I cite these examples of the Board's comments on a space station to illustrate that, contrary to some current accounts, the Board has never taken a position "against" a space station either in the past or in its March 1991 statement. On the contrary, in the March statement, the Board declared, "The Space Studies Board strongly endorses the position that a space-based laboratory is required to study the physiological consequences of long-term space flight."

In the context of Mission from Planet Earth as a national goal, the Board emphasizes that the driving force for space station life sciences research is not based on abstract scientific merit, but rather on its role as *a*, if not *the*,

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[3] *Space Science in the 21st Century—Overview* (NAP), 1988, p. 82.

[4] Reference 1, p. 26.

[5] *Space Studies Board Position on Proposed Redesign of Space Station Freedom*, March 1991.

[6] *A Strategy for Space Biology and Medical Science for the 1980s and 1990s* (NAP), 1987.

[7] Testimony to the U.S. Senate Subcommittee on Science, Technology, and Space, May 1990.

critical factor in determining the feasibility of the Administration's vision of human space exploration. The primary research requirement for a space station is therefore based on the need to perform the life sciences research necessary to support a national goal of long-duration human spaceflight. This was also the conclusion of the Augustine Committee. While there may be unrelated, but scientifically interesting, life sciences experiments that could be conducted in a low-gravity environment, these experiments alone could not justify building a space station. There are, however, several absolutely critical requirements for an effective and efficient program of the necessary space biology and medicine research. The Board notes particularly that investigation and solution of many of the fundamental problems in space life sciences will require long periods of time. The critical research requirements are described in detail in the Board's 1987 research strategy.[8] Briefly, they include the following:

1. *A Dedicated Life Sciences Laboratory*—because of the need for continuous access and human intervention;
2. *Focused Missions*—which would allow sufficient flight time to collect reliable results, to replicate experiments when necessary, and to change protocols as data are gathered and interpreted;
3. *Flexibility*—in terms of equipment, experimental organisms, and scheduling of experiments;
4. *Facilities*—(a) a variable force centrifuge; (b) a research animal holding facility and a plant growth chamber, including supporting analytical equipment for handling and analysis of cell and tissue specimens, and a system for preservation and storage of blood, urine, and stool samples; and (c) computational facilities;
5. *Research Personnel*—well-trained, skilled scientists in appropriate disciplines and in sufficient numbers to produce reliable results;
6. *Research Animals*—as subjects for experiments to study adaptation to microgravity and to develop countermeasures for microgravity's effects.

Since the release of the Board's March statement, NASA has informed us that it is now committed to providing a 2.5-meter centrifuge on the first assembly flight following permanently manned capability (PMC). This was a welcome announcement because of the centrifuge's absolutely critical role in the conduct of meaningful research. It is important to note for the record, however, that under this plan, research critical to planning for Mission from Planet Earth cannot be started until after 2000, when the centrifuge becomes available. In recent testimony before the Senate, NASA's Associate Administrator for Space Science and Applications, Dr. Lennard Fisk, stated that, even in an optimistic scenario, fully validated life science results bearing on long-duration human spaceflight would not become available until 2007. Further, development of the centrifuge and supporting facilities will require a significant infusion of new funds that are not identified in the existing budget agreement for the station. It is this inconsistency between the accepted principal mission of the space station program and the existing planning and funding approach that I would like to highlight for this subcommittee.

I would like to note also that, aside from concerns about the centrifuge, other concerns raised by the Board in its March statement still remain—insufficiently defined power requirements and availability, lack of adequate crew to conduct experiments and serve as subjects, and the absence of either a dedicated laboratory or plans for focused missions. NASA and the Board have agreed to continue to meet to discuss these matters further.

SUMMARY

In conclusion, Mr. Chairman, the Space Studies Board has found much to like in NASA's FY92 budget proposal. Some valuable progress is evident in important areas, such as the growth in R&A budgets for life sciences and planetary exploration. There are some areas of concern, however, particularly in technology support for unmanned missions and in a perceived serious mismatch between space station development plans and objectives. The members of the Space Studies Board and of its discipline committees are committed to working with NASA and the national space policy community to help bring about the most productive, cost-effective, and exciting space program the taxpayers' investment can deliver.

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[8] Reference 6.

5.5 Testimony on the NASA Fiscal Year 1992 Budget Proposal (Senate)

Space Studies Board Chair Louis J. Lanzerotti delivered the following testimony before the Subcommittee on VA, HUD, and Independent Agencies of the Committee on Appropriations of the U.S. Senate on May 17, 1991.

Thank you for inviting the Space Studies Board to testify on NASA's FY92 budget proposal. The Board was briefed by NASA officials on the budget during a Board meeting in late February; our testimony today is based on ensuing Board discussion on these and other matters related to the U.S. civil space program.

The Space Studies Board was established in 1958 by the National Academy of Sciences to provide guidance to NASA and other agencies concerned with civil space research. Over the years, the Board has prepared and released numerous reports and research strategies intended to promote the success and vitality of the U.S. civil space program. Board recommendations are based on focused discussions among the prominent researchers who constitute its standing committees and task groups. These committees and task groups have addressed, over the years, a broad sweep of space science and applications disciplines, including astronomy and astrophysics, space biology and medicine, microgravity research, solar and space physics, earth studies, and planetary and lunar exploration.

I would like to divide my remarks today into three general parts: the first is an assessment of the overall funding proposal for NASA relative to the recommendations of the Advisory Committee on the Future of the U.S. Space Program[1] (the "Augustine Committee"); the second includes several consensus views on narrower topics from our February Board meeting; and the third concerns the restructured space station.

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Before remarking on NASA's FY92 budget proposal, I would like to remind those present that I was a member of the Augustine Committee. Having said this, I would also like to state that the Space Studies Board concurs broadly with many of that committee's recommendations. The Augustine Committee recommended a near-term real dollar increase of 10% per year for NASA, a figure closely approximated by the currently proposed budget increase of 14%, once inflation is taken into account.

Beyond endorsing the proposed aggregate budget increase, the Board is solidly supportive of the primary importance assigned by the Augustine Committee's report to the role of space science as the "fulcrum" of our civil space program. Although there has been some discussion within the Board as to whether the present fraction of the total budget adequately reflects the primacy of this role, the Board strongly endorses the principle of the statement.

The recommendation that the Mission to Planet Earth (MTPE) and the Mission from Planet Earth (MFPE) be undertaken in that priority order was also sympathetically received by the Board. I would like to call attention, however, to an important related suggestion made in the Augustine Committee's report:

> The large size, broad scope and national importance of the U.S. Global Change Research Program also suggest that the EOS funding be provided as a line item, separate from other science programs.[2]

The Board is concerned that if MTPE programs are not isolated from core elements of the Office of Space Science and Applications (OSSA) program, the long duration and vast scope of the EOS and precursor missions, taken together, could seriously impact the resources available to these core research programs.

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First, decisions will soon be made on the technical approach for correcting the optical deficiencies of the Hubble Space Telescope. The Board believes that evaluation of the Corrective Optics Space Telescope Axial Replacement (COSTAR) repair option, and any decision on its implementation, should consider not only its cost, schedule, and engineering feasibility, but also trade-offs with, and impacts on, second-generation Hubble instruments. The costs of Hubble repairs and upgrades subsequently undertaken should be closely monitored and controlled to minimize effects on other OSSA programs.

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Second, advances in robotics capability are essential to NASA's space science and applications programs. The value of robotics to the unmanned exploration program has significant demonstrated benefits to scientific research, irrespective of the status or existence of a human exploration program. The Board is concerned about the deletion of robotic exploration technology funding for planetary rover, sample acquisition, and autonomous rendezvous, docking, and landing. The Board recommends that support for these efforts be restored, and, if possible, augmented.

Research and Analysis

Third, the Board reaffirms its position that vigorous research and analysis (R&A) and suborbital research programs are essential to the overall vitality of the national space research agenda.[3] The Augustine Committee also emphasized the importance of these programs.[4] NASA should take steps to ensure healthy growth in these budgets and to protect them from encroachment by troubled major flight projects. In particular, the Board strongly supports the proposed targeted increases in life sciences and planetary exploration R&A.

THE RESTRUCTURED SPACE STATION

As you know, the Board recently released a statement expressing serious reservations about the science capabilities of the restructured space station design.[5] This statement has unfortunately been misinterpreted in some quarters. I would like to take this opportunity to state clearly, for the record, that the Space Studies Board is not now, and has never been in the past, opposed to the concept of a space station or to a national goal of long-duration human spaceflight. A 1983 position of the Board on the scientific value of a space station, written in response to a request from NASA, assessed the possible utility of a space station for accomplishment of the major scientific objectives of all space research disciplines (except microgravity research). The Board concluded that *most* of these goals could be met using other means, with the *exception* of space biology and research on human adaptation and survival in long-duration spaceflight. The Board published a research strategy for space biology and medicine in 1987[6] in which the requirement for a space station for this discipline was described as *pivotal*. The Board has also testified before Congress on science requirements for a space station on several occasions. In May 1990, the Board expressed " . . . continuing concern about the utility of the space station as now planned, for microgravity, life sciences, and for the research necessary [to support] long duration spaceflight." [7]

I cite these examples of the Board's comments on a space station to illustrate that, contrary to some current accounts, the Board has never taken a position "against" a space station either in the past or in its March 1991 statement. On the contrary, in the March statement, the Board declared, "The Space Studies Board strongly endorses the position that a space-based laboratory is required to study the physiological consequences of long-term space flight."

In the context of Mission from Planet Earth as a national goal, the Board emphasizes that the driving force for space station life sciences research is not based on abstract scientific merit, but rather on its role as *a*, if not *the*,

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[3] *Space Science in the 21st Century—Overview* (NAP), 1988, p. 82.

[4] Reference 1, p. 26.

[5] *Space Studies Board Position on Proposed Redesign of Space Station Freedom*, March 1991.

[6] *A Strategy for Space Biology and Medical Science for the 1980s and 1990s* (NAP), 1987.

[7] Testimony to the U.S. Senate Subcommittee on Science, Technology, and Space, May 1990.

critical factor in determining the feasibility of the Administration's vision of human space exploration. The primary research requirement for a space station is therefore based on the need to perform the life sciences research necessary to support a national goal of long-duration human spaceflight. This was also the conclusion of the Augustine Committee. While there may be unrelated, but scientifically interesting, life sciences experiments that could be conducted in a low-gravity environment, these experiments alone could not justify building a space station. There are, however, several absolutely critical requirements for an effective and efficient program of the necessary space biology and medicine research. The Board notes particularly that investigation and solution of many of the fundamental problems in space life sciences will require long periods of time. The critical research requirements are described in detail in the Board's 1987 research strategy.[8] Briefly, they include the following:

1. *A Dedicated Life Sciences Laboratory*—because of the need for continuous access and human intervention;
2. *Focused Missions*—which would allow sufficient flight time to collect reliable results, to replicate experiments when necessary, and to change protocols as data are gathered and interpreted;
3. *Flexibility*—in terms of equipment, experimental organisms, and scheduling of experiments;
4. *Facilities*—(a) a variable force centrifuge; (b) a research animal holding facility and a plant growth chamber, including supporting analytical equipment for handling and analysis of cell and tissue specimens, and a system for preservation and storage of blood, urine, and stool samples; and (c) computational facilities;
5. *Research Personnel*—well-trained, skilled scientists in appropriate disciplines and in sufficient numbers to produce reliable results;
6. *Research Animals*—as subjects for experiments to study adaptation to microgravity and to develop countermeasures for microgravity's effects.

Since the release of the Board's March statement, NASA has informed us that it is now committed to providing a 2.5-meter centrifuge on the first assembly flight following permanently manned capability (PMC). This was a welcome announcement because of the centrifuge's absolutely critical role in the conduct of meaningful research. It is important to note for the record, however, that under this plan, research critical to planning for Mission from Planet Earth cannot be *started* until after 2000, when the centrifuge becomes available. In recent testimony before the Senate, NASA's Associate Administrator for Space Science and Applications, Dr. Lennard Fisk, stated that, even in an optimistic scenario, fully validated life science results bearing on long-duration human spaceflight would not become available until 2007. Further, development of the centrifuge and supporting facilities will require a significant infusion of new funds that are not identified in the existing budget agreement for the station. It is this inconsistency between the accepted principal mission of the space station program and the existing planning and funding approach that I would like to highlight for this subcommittee.

I would like to note also that, aside from concerns about the centrifuge, other concerns raised by the Board in its March statement still remain—insufficiently defined power requirements and availability, lack of adequate crew to conduct experiments and serve as subjects, and the absence of either a dedicated laboratory or plans for focused missions. NASA and the Board have agreed to continue to meet to discuss these matters further.

SUMMARY

In conclusion, the Space Studies Board has found much to like in NASA's FY92 budget proposal. Some valuable progress is evident in important areas, such as the growth in R&A budgets for life sciences and planetary exploration. There are some areas of concern, however, particularly in technology support for unmanned missions and in a perceived serious mismatch between space station development plans and objectives. The members of the Space Studies Board and of its discipline committees are committed to working with NASA and the national space policy community to help bring about the most productive, cost-effective, and exciting space program the taxpayers' investment can deliver.

[8] Reference 6.

6
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Appendix
Prior Year Letter Reports on the Space Station

In February 1991, the Board assessed the results of the 1990/1991 redesign of the space station and described the results of the study in a letter to NASA Administrator Richard Truly in a letter dated March 14, 1991. This report followed a series of letters on the space station program that began with a Board discussion with Administrator James Beggs of "the space station concept" in 1982. This was followed by additional reports on aspects of the program prepared and delivered in 1983, 1987, 1989, and 1990. Since the later reports elaborate and extend advice in the previous correspondence, it is helpful to have these earlier documents available for reference. To meet this need, the texts of these forerunner letters are provided here for convenient use.

Section A.1 provides the original letter to Administrator Beggs in 1982 on the general place of a manned orbital laboratory within the space science planning of the time; Section A.2 is a letter and attachments sent to Administrator Beggs in 1983 that elaborate on the 1982 communication; Section A.3 is a letter sent to Space Station Program Manager Andrew Stofan in 1987 on life sciences requirements; and Section A.4 presents a letter to Assistant Associate Administrator Joseph Alexander on the subject of cabin atmosphere for the station.

These earlier letters furnish the background for the Board's 1991 study and resulting Board advice that are reported in Section 4.1.

A.1 Report to Administrator Beggs: 1982

Thomas M. Donahue, Chairman of the Space Science Board, sent the following letter to James M. Beggs, NASA Administrator, on September 13, 1982.

The Space Science Board appreciates that it had the opportunity to meet with you and to discuss, among other things, the space station concept. We share your view that initiating such a program will require a national commitment based on considerations that range beyond its use in support of either space science or applications. Nevertheless, we believe that if a station is developed it should be compatible with the objectives of space science to the degree that those requirements do not unreasonably increase the station's cost or substantially limit its ability to meet other national objectives. As you know, the Board has no position with regard to a space station; the Board, however, accepts the opportunity to set forth the technical capabilities required in order to address the objectives of the Board's scientific strategies. We believe that these requirements should be considered during the conceptual definition phase of any space station system.

The Board emphasizes, however, that effective utilization of a space station system addressing these objectives will depend on the availability of resources beyond those required for the development of the space station. An adequate capability to support space science objectives for the next two decades already exists in the Space Shuttle augmented with appropriate upper stages. On the other hand, the current level of support for some disciplines is not sufficient for a viable program whether based on the shuttle or a future space station. Under these circumstances, the Space Science Board is apprehensive about the possible adverse consequences of the cost of a space station on the national capability for conducting a vigorous scientific program during the next two decades.

The degree to which a space station system would afford opportunities for significant advances in space science depends on the extent to which:

1. Viable space science research is maintained, and important experimental and theoretical endeavors in space science are continued and initiated while the space station system is being developed. If a space station is to have a strong scientific component, financial support for scientific activity must be assured and protected during the course of station development, construction and operation.
2. The operational space station system provides a sufficient number and variety of space science flight opportunities, many involving unmanned spacecraft, on an appropriate time scale.
3. The operational system provides the necessary space platform environments and capabilities, such as low contamination and adequate pointing accuracy, required for space science observations.
4. The necessary capabilities for carrying out space science observations, including achieving the required Earth orbits and reaching extraterrestrial targets, are an integral part of the space station system and not a later or lower priority development.

I have asked the Board's Committees to consider the requirements their scientific strategies would impose on a space station system and expect to have at least a preliminary compilation of those requirements at the time of the Board's next meeting in November 1982.

Signed by
Thomas M. Donahue
Chairman, Space Science Board

A.2 Report to Administrator Beggs: 1983

Thomas M. Donahue, Chairman of the Space Science Board, sent the following letter and attachments to James Beggs, NASA Administrator, on September 9, 1983.

Last September the Space Science Board agreed to work with NASA in determining the technical capabilities a space station should have in order to address effectively the scientific objectives of the various space science disciplines. During the past year, the Board and its committees have had frequent interactions with the NASA Space Station Task Force, led by John Hodge, in fulfilling that commitment. We have been very favorably impressed by the careful consultation with the community of potential space station users that NASA has maintained during this exercise. In due time, we plan to transmit to you formally the results of the past year exercises by the Board and its committees.

Mr. Hodge has briefed the Board concerning the characteristics of the space station now being proposed by NASA. In the reports enclosed with this letter, the Board addresses two separate issues. The first issue is the degree to which the space station now being considered will be required in order to reach the objectives of the Space Science disciplines during the next twenty years. This evaluation, in the Board's opinion, must be made in the light of the adequacy of the presently available space transportation system to meet space science needs without augmentation by the proposed space station capabilities. Our finding is that present systems are adequate to these needs. Therefore, on the issue of meeting the needs of space science, our recommendation would be to use the space shuttle, together with requisite upper stages, maneuvering and propulsion systems for missions to be flown during this century. To meet longer range science objectives, a space station might prove to be very useful in various ways if it were suitably designed. The Board would be happy to work with you to define such a space station if you proceed with plans for it.

As we pointed out in our letter of September 13, 1982, the Board agrees with you that the question of whether to go forward with a space station is not apt to be made on the grounds of its usefulness to space science and applications alone. Thus, the report entitled *Space Science Board Assessment of the Scientific Value of a Space Station* should not be regarded as establishing a Board position on the question of whether the nation should or should not now or in the future develop such a space station. On the other hand, the Board has considered some additional issues that lie within its competence. These have to do with conditions that should exist as any space station is being developed and after it becomes operational, if a healthy and vigorous space science program is to be maintained concurrently. A discussion of these issues is the content of our second report, *Space Science in a Space Station Era*, which is also being forwarded to you with this letter.

Signed by
Thomas M. Donahue
Chairman, Space Science Board

SPACE SCIENCE BOARD ASSESSMENT OF THE SCIENTIFIC VALUE OF A SPACE STATION

During the past year, the Space Science Board has examined the question of what space systems are required to launch and support adequately the space science missions designed to attain the high priority science objectives identified by the Board and its committees. These missions are very numerous, challenging, and exciting. However, the rate at which they are launched would have to increase significantly above the current rate if all of the missions needed to fulfill this program are to be flown during the next two decades. The means of launching and tending them is now available or being developed in the form of expendable launch vehicles and the space shuttle, augmented as required by adequate high energy upper stages. One reason for the present slow pace is the delay in bringing the shuttle and its upper stages to full operational status. Another is that we have not yet learned how to use the shuttle efficiently and effectively as a manned orbiting laboratory. The Space Science Board urges that the present launch systems be fully and flexibly exploited and adequate resources be brought to bear so that the stated objectives of space science can be reached in a timely fashion. The results of following this course should be a rich harvest of discoveries and insights in all disciplines of space science.

The Space Science Board has carefully examined the proposal by NASA for a manned space station in low Earth orbit designed to engage in a number of major activities. A significant portion of these activities involves support of space science missions. The Board has also examined the set of specific missions proposed for implementation from the space station system during the years 1991-2000. It has found that few of these missions would acquire significant scientific or technical enhancement by virtue of being implemented from this space station. In view of this and the adequacy of the present space transportation system for the purposes of space science, the Board sees no scientific need for this space station during the next twenty years.

In the longer term, the Space Science Board sees the possibility that a suitably designed space station could serve as a very useful facility in support of future space science activities. Such a space station could provide means for erecting and fabricating large and novel structures in space, and for servicing, fueling, and retrieval of payloads in orbit. If NASA wishes to develop plans for such an ambitious and technically demanding space station for the next century, the Space Science Board would be pleased to work with NASA in defining the properties of such a space station.

SPACE SCIENCE IN A SPACE STATION ERA

In a recent statement entitled, "Space Science Board Assessment of the Scientific Value of a Space Station," the Space Science Board has addressed the issue of the space science need for a space station. It found no need for a space station to support missions addressing high priority science issues for the next two decades. On the other hand, it found that a suitable space station could offer important services to space science in the more distant future.

The Space Science Board realizes that the nation may decide to commit itself to the deployment of a space station in support of needs and objectives other than or in addition to those of space science alone. The characteristics of such a space station should be carefully determined to conform to the principal activity that it is intended to support. For example, it is not obvious that a space station optimized as a transportation node for travel between the Earth and other solar system objects would also be an entirely suitable platform from which to launch and support science and applications missions. Whatever the eventual properties of such a space station, there will probably be a set of high priority science missions that require orbits and operational support for maximum effectiveness other than those available from that station. If a space station program should be undertaken and it is meant to be useful to space science, the Space Science Board urges that the means to initiate and operate space science missions in a timely fashion and in reasonable accord with priority ordering of those missions be maintained. Ordering of missions would then be determined by scientific priority rather than the nature of the launch or support system required. The Board also urges that the scientific program be structured so as to be protected from delay in space station development or changes in its capability.

The Board also wishes to make the following specific recommendations and observations.

Scientific instruments that can be deployed in orbits compatible with space station orbits should be flown in optimal scientific orbits and on separate platforms if that is necessary to preserve them from contamination, interference, and degradation of pointing stability and control that may be associated with the manned modules.

If the space station is designed to provide a servicing capability beyond that provided by the shuttle, that capability should allow retrieval of instruments from a wide variety of orbits.

The deployment of a space station designed in part to support space science implies an increase in the level of space science activity above that presently planned. If such a space station is to be utilized effectively, the space station system should be accessible and affordable for scientific use, and there should be a real increase in the level of support for that activity.

A commitment by the nation to long duration human space flight, whether in Earth orbit or beyond, calls for the establishment of a facility for space biological and medical research on the effects on individuals of very long exposure to the "low g" environment. In this sense, the relationship of the life sciences to a space station is a special one.

Thus, a manned space station could eventually provide significant opportunities for a number of disciplines in space science provided there is a commensurate increase in the total level of space science activity. Realization of those opportunities would depend on the extent to which the capability to carry out space science research is kept viable, important experimental and theoretical activity is continued, and new endeavors are initiated while the

space station is being developed. After the space station becomes operational, realization of those opportunities would depend on the provision of a sufficient number and variety of flight opportunities, many involving unmanned space craft and flight to regions of space near the Earth and further out in the solar system at distances and locations inaccessible to a manned platform.

A.3 Report to Space Station Program Manager Stofan: 1987

L. Dennis Smith, Chairman of the Committee on Space Biology and Medicine, sent the following letter to Andrew Stofan, NASA Associate Administrator for the Office of Space Station, on July 21, 1987.

The Space Science Board's Committee on Space Biology and Medicine has recently published a report: *A Strategy for Space Biology and Medicine for the 1980's and 1990's*. In it, we have made two very strong recommendations for the space station: (1) a Variable Force Centrifuge of the largest possible dimensions, and (2) a Dedicated Life Sciences Laboratory.

As NASA is actively engaged in planning the design of the space station and making decisions about its initial configuration, we felt compelled to bring these recommendations to your attention while there is still time to affect these decisions and to maximize the station's usefulness to space biology and medical research.

Unlike the more traditional space sciences, which are primarily observational with essentially no control of the phenomena under study, space biology and medicine require interactive experimental approaches. Establishment of new ideas frequently requires intervention in experimental design during the course of experiments, often resulting in modification of hypotheses and generation of new ideas. A permanently occupied Space Station will, for the first time, permit relatively long-term laboratory experiments to be performed in a microgravity environment using the empirical methods so successfully employed in hundreds of laboratories on Earth. In this sense, the necessity of a space station for life sciences research is unique.

The field of space biology and medicine is in its infancy. It has been based on ground-based research coupled with limited flight opportunities which, in some disciplines, has allowed the generation of models. They can only be verified by sustained experimental opportunities in space which are also required to create and verify new models. It is safe to say that without dedicated opportunities on the space station, space biology and medicine will not evolve much further as a discipline. That would, in turn, preclude any long term human presence in space.

In its report, the Committee on Space Biology and Medicine makes the following recommendation:

> We have been apprised of the engineering problems involved in the inclusion of a large centrifuge in a freely floating Space Station. The committee still recommends that a Variable Force Centrifuge (VFC) of the largest possible dimensions be designed, built, and included in the initial operating configuration of the Life Sciences Laboratory. It does so because a VFC is an essential instrument for the future of space biology and medicine.

The VFC not only provides an onboard 1-g control for experiments concerned with the effects of microgravity on biological processes, it also provides the opportunity to study the effects of varying gravitational forces on such processes. Concerning the deleterious effects of microgravity that have already been documented, a VFC will allow investigators to determine also whether there is a threshold force required for a response to occur or, conversely, to reverse a given response. The centrifuge should be large enough to accommodate experiments on primates, possibly humans, rodents, and larger plants. A VFC is an essential instrument for the future of space biology and medicine.

The Space Science Board has documented the need for a centrifuge for space biology and medical research in a number of published reports. Every other group that advises NASA on life sciences issues supports this recommendation. They range from the President's National Commission on Space to the Task Force on Scientific Uses of the Space Station and the NASA Life Science Advisory Committee.

To summarize, of the facilities that have been recommended for medical and biological research on Space Station, there is uniform support in the life sciences community for giving highest priority to inclusion of the VFC in the Initial Operating Configuration. It would be of greatest value when coupled with a dedicated Life Sciences Laboratory. Thus, for maximum advantage, the VFC should be included as part of a Life Sciences Laboratory or a node connected to a dedicated life sciences module.

Signed by
L. Dennis Smith
Chair, Committee on Space Biology and Medicine

A.4 Report to Assistant Associate Administrator Alexander: 1990

Louis J. Lanzerotti, Chairman of the Space Studies Board, sent this letter and attachment to Joseph K. Alexander, NASA Assistant Associate Administrator for Science and Applications, on December 12, 1990.

Thank you for your letter of November 9, 1990, requesting that the Space Studies Board (SSB) provide its views and recommendations concerning the contemplated reduction in Space Station Freedom's (SSF) pressure to a 10.2 psi/"normoxic" level and the current 90-day study activity. To provide a timely response, the SSB's Committee on Space Biology and Medicine and Committee on Microgravity Research met together on November 28, 1990, to hear briefings from NASA personnel as input to developing the SSB's recommendations.[1] The conclusions and recommendations transmitted in this letter report are based on information presented at that meeting as well as on the Board's and its Committees' ongoing interactions with NASA concerning SSF. Attachment A contains illustrative examples of some of the specific relevant materials science issues, both in terms of research and safety, and space biology and medicine issues, both in terms of research requirements and clinical considerations. Because of the very limited time in which the Board has been asked to respond, it does not consider this list exhaustive or complete.

The Board has presented its views and recommendations concerning SSF and user considerations on a number of occasions. Most recently in its testimony of May 1990 to the Senate Subcommittee on Science, Technology, and Space, the Board commented on SSF as it was then contemplated.

> There have been a multitude of recommendations from advisory committees that were created to advise on the scientific requirements for the station. However, current proposals for Space Station Freedom suggest that it may not be of optimum use to the two primary communities for which it is intended—the life sciences and microgravity sciences. The Board and several of its committees have had an ongoing dialogue with NASA about the space station since its inception. We will continue to do so as it evolves and is eventually deployed . . . . [I]n the context of "responsiveness" [we] feel it is our responsibility to advise the Subcommittee of our continuing concern about the utility of the station if it proceeds as currently planned. This is a multi-billion dollar research effort that must incorporate the requirements of the research it is meant to facilitate, particularly [if] we move forward to research prerequisites for a human exploration program.[2]

In 1983, in a letter response to a request concerning science use of a space station from then NASA Administrator James Beggs, the Board stated:

> A commitment by the nation to long duration human space flight, whether in Earth orbit or beyond, calls for the establishment of a facility for space biological and medical research on the effects on individuals of very long exposure to the "low-g" environment. In this sense, the relationship of the life sciences to a space station is a special one . . . a manned space station could eventually provide significant opportunities for a number of disciplines in space science.[3]

The Board has made recommendations concerning use of a space station in several SSB reports published during the 1980s: *Space Science in the Twenty-First Century—Life Sciences* and *Space Science in the Twenty-First Century—Fundamental Physics and Chemistry* (National Academy Press, Washington, D.C., 1988) as well as *A Strategy for Space Biology and Medical Science for the 1980s and 1990s* (NAP, 1987). The latter report outlines a detailed research strategy for which the availability of a space station is pivotal. It includes specific recommendations for dedicated blocks of time for medical and biological subdisciplines, research questions, and essential instruments and facilities on a space station.

SSB ASSUMPTIONS

Understanding that your request to the Board arises from a congressionally mandated 90-day study and a set of rapidly changing scenarios and options, the SSB concluded that its advice should be given in some mutually

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[1] November 28, 1990, briefings: OSSA Space Station Freedom restructure study guidelines, R. Rhome; presentation to the National Academy of Sciences CMGR/CSBM, A. Nicogossian; atmosphere and hypoxia, J. Kerwin; Space Station Freedom presentation, W. Taylor; letter from CMGR member W. Sirignano to R. Sekerka re fire safety and combustion (with attachment); and letter from Lewis Research Center re fire safety and materials science issues.

[2] Space Studies Board testimony to the Senate Subcommittee on Science, Technology, and Space, May 10, 1990.

[3] Space Science Board letter report to NASA Administrator James Beggs, September 9, 1983.

understood context if it is to be both credible and useful. Thus, the Board has agreed on a defined set of assumptions that, in turn, lead to its overall recommendations in response to your request. These assumptions are as follows:

1. The avowed purpose of SSF is to provide a research laboratory, primarily for materials science and space biology and medicine. (This purpose has been stated to the Board itself, to various of its Committees, and to congressional committees and others on a variety of occasions over the past five years.)

2. A permanent human presence in space and exploration of the Moon and Mars is a national goal of public record.

3. The primary, if not sole, driver behind a desire to lower the pressure of SSF to 10.2 psi/"normoxic" atmosphere during assembly of the facility is the need for extensive extra vehicular activity (EVA) in the shuttle-rated suit currently available.

SSB CONCLUSIONS

The views and recommendations of the Space Studies Board are based on several fundamental conclusions. Attachment A contains elaborations of some of these points. Space Station Freedom should be designed and operated to maximize accommodation to users, be it the science community, commercial interests, or national security. If SSF is, as has been declared, intended as a means to advance scientific understanding, it must be built to facilitate scientific research.

The largest and most extensive data base that exists for biological and medical research was obtained at 14.7 psi—the atmospheric pressure close to that at sea-level. If results obtained in space research on the relatively few available subjects are to be useful and meaningful, they must be compared to the body of scientific knowledge, obtained in ground-based studies, that exists today. While the Board is aware that some ground-based research has been conducted at various high-altitude locations on Earth, most of the extant data is from near-sea-level environments. The Board cannot endorse a decision associated with the descoping activity that would require building new ground-based facilities to conduct additional research in order to create a new set of control data for comparison with data obtained in space-based experiments. This would require significant additional expenditures of both time and public funds that are not readily available. At the same time, optimum long-term atmospheric conditions for the Space Exploration Initiative (SEI) should be identified now and pursued as part of the SSF science objectives and designs. Data must be obtained to support these conditions.

A major concern about fire safety is associated with a 10.2 psi/"normoxic" atmosphere: the likelihood of spontaneous ignition increases, and the rate for the spreading of such a flame increases with the increasing fraction of oxygen. (From this perspective, the fraction of oxygen should actually be decreased to improve fire safety, not increased, as would be the case if the SSF pressure were lowered to 10.2 psi/"normoxic".) Providing for SSF fire safety is a tremendous challenge. Anything that might reduce the probability of ignition and/or the spread rate of flame must be fully explored.

SSB RECOMMENDATIONS

From both a scientific utilization as well as a fire safety perspective, the Board is convinced that maintaining a 14.7 psi/21% oxygen atmosphere on SSF is much preferred. The Board's primary recommendation is that a high-pressure space suit be designed and procured that would allow for performing EVA without the extensive preparations required with the suit currently available. In addition, because of the serious concerns regarding fire safety, NASA should conduct a study on the potential effects of reducing the oxygen fraction from the normal sea-level value. In particular, the study should address a reduction of the oxygen percentage below 21%.

If it ultimately proves necessary to lower the SSF's cabin atmosphere to 10.2 psi/"normoxic" (or other levels lower than 14.7) during SSF assembly, the Space Studies Board strongly recommends the following actions, at a minimum:

1. SSF should be designed from the very beginning to accommodate a range of atmospheric pressures and oxygen ratios from 10.2 psi/"normoxic" to 14.7 psi, and a firm commitment should be made to ultimately operate at 14.7 psi.

2. During the man-tended capability phase (SSF assembly period), the station should be operated at 14.7 psi at all times that EVA is not scheduled, i.e., both for "utilization flights" and the periods between shuttle flights to the station.

3. From the point of permanent manned capability (PMC) forward, the station's pressure should be maintained at 14.7 psi/21% oxygen at all times.

4. NASA should provide a control chamber at 14.7 psi/21% oxygen in which to conduct plant and animal experiments.

Accommodation of scientific requirements for SSF must be fully considered and reviewed. Briefings at the November 18, 1990, meeting suggest that many options being considered as part of the 90-day SSF study could have a major impact on the availability of other resources—power, experiment operation time, data communications bandwidth, and inertial/rotational acceleration characterization and control during the early man-tended phase. The Board recommends that great care and consideration be taken to ensure that the man-tended phase of SSF is the most cost-effective way to achieve the scientific objectives of the microgravity and life sciences research programs. For example, would an extension of Spacelab capability through SSF assembly be of greater value than relying on the Space Station during that period?

In conclusion, the Board understands that Space Station Freedom has been, and likely will continue for some time to be, the subject of debate. The Board believes this is healthy and appropriate, both because of the SSF's potential as a major national resource and its associated significant costs. At the same time, the Board takes the position that at some point in the discussion and decision process, agreement as to the station's purpose and function must be reached by all concerned—the SSF's supporters and critics—with NASA, the user community, Congress, industry, and the public. If the decision is made to proceed with the project, all involved should do so honestly and with a common sense of purpose. The Board supports the position taken in a 1988 report to President-Elect Bush, that

> . . . some form of space station is essential to establish the feasibility of extended human space flight. It is the only way to properly research the need for artificial gravity in extended manned missions and to develop the necessary technology for these missions.[4]

The Board looks forward to assisting NASA in whatever ways are possible as plans and decisions concerning Space Station Freedom are finalized.

Signed by
Louis J. Lanzerotti
Chairman, Space Studies Board

ATTACHMENT A

Illustrative Examples of Microgravity Science Issues and Space Biology and Medicine Issues Associated with Space Station Freedom Cabin Atmosphere

Microgravity Science

1. The Space Studies Board concludes that the 10.2 psi/"normoxic" atmosphere being considered for Space Station Freedom (SSF) will have no effect on microgravity experiments that will be conducted in closed containers. Experiments requiring other than 10.2 psi/"normoxic" ambient pressures can be contained in gloveboxes or with appropriate gas-handling systems that are planned for SSF experiment hardware as of this time.

2. If the SSF cabin pressure were lowered to 10.2 psi/"normoxic", it might be necessary because of potential fire hazard, to eliminate certain materials (virtually all nonmetals), a likely source of additional costs. Fire-extinguishing and air filtration systems would be required to mitigate additional risks. These issues require further study.

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[4] National Academy of Sciences and National Academy of Engineering, *Toward a New Era in Space: Realigning Policies to New Realities* (National Academy Press, Washington, D.C., 1988).

3. Potential impacts of a reduced pressure on control of the thermal environment should be studied in greater detail. Much of the avionics on SSF will be performed by forced gas circulation, at reduced pressures; increased linear flow velocities may be required to manage avionics and payload heat loads.

Space Biology and Medicine

1. The major argument against lowering the SSF cabin pressure to 10.2 psi/"normoxic" is the extensive ground-based data base that exists as a control for data obtained in space-based experiments.

2. A variety of experimental data from studies on hypobaric physiology have demonstrated that low pressure *per se* has major effects. These include a shift of fluid from the lower part of the body toward the head and thorax, increased excretion of water and salt, orthostatic hypotension, muscle atrophy (particularly of antigravity muscles), bone demineralization, a reduced glomerular filtration rate as measured by creatinine clearance, a reduction of vital capacity (e.g., reduced levels of aldosterone, glucorcortocoids, and angiotension), and increased body temperature and associated thermal discomfort. These all represent changes observed in microgravity. Unfortunately, there is a perception that since experiments in space have been performed under a variety of atmospheric conditions, ranging from 5 psi to 14.7 psi (oxygen ranging from 21% to 100%) with no dramatic difference in physiological changes, variable atmospheres are not of concern. There are no conclusive data that support this conclusion.

3. As the construction and maintenance of the SSF will involve much greater EVA time than has ever been undertaken, the risk of astronauts being subjected to bends must be minimized.

4. A lower cabin pressure would have an unfavorable effect on plant research. Although plants could probably survive under conditions of lower pressure, the consequences of forcing photosynthetic organisms to perform under such conditions could produce undesired results both in terms of research return and goals associated with food production in space. Examples of some of the deleterious effects are significant reductions in photosynthesis, and the effects of reduced pressure on critical processes such as transpiration. Developmental processes mediated by volatile plant hormones might also be affected, resulting in alterations in growth and such parameters as seed set and fruit ripening.

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