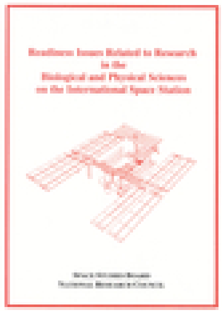

Readiness Issues Related to Research in the Biological and Physical Sciences on the International Space Station

Task Group on Research on the International Space Station, Space Studies Board, National Research Council

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Task Group on Research on the International Space Station
Space Studies Board
Division on Engineering and Physical Sciences
National Research Council

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Preface

In the 1980s and 1990s most microgravity research in space in the life and physical sciences was conducted on the space shuttle. The Spacelab module, which provided a relatively large volume in which to house research equipment in a crew-tended, shirtsleeve environment in the shuttle cargo bay, comprised the most useful platform for these shuttle-based investigations. The Spacelab series of flights was terminated in 1998. Although a small number of shuttle flights have occurred or are planned for the next few years using alternative research platforms, most future research activities must now await the availability of the completed International Space Station (ISS) in the 2006 time frame.

Such a hiatus in access to space has concerned many researchers. It has been feared that this gap could lead to the atrophy of the existing research community as researchers turn elsewhere to pursue more immediate research opportunities and graduate students and postdoctoral fellows view low-gravity studies as being too far in the future to merit their attention. Concerns have also been expressed about how this situation will reduce the size of the research community below the critical mass needed to use the ISS meaningfully when its assembly and outfitting are completed. In several reports to NASA, the Space Studies Board has stressed the need to continue to provide research flight opportunities up to the time that the ISS becomes available.

The House of Representatives raised this issue in 1999 during formulation of a proposed NASA authorization bill, but no final bill was enacted that year. However, the NASA Authorization Act of FY 2000 became law, and it contained provisions directing NASA to seek a study by the National Research Council (NRC) and the National Academy of Public Administration (NAPA) on these issues.

The Space Studies Board of the NRC, in cooperation with the National Academy of Public Administration, agreed to organize a study of the status of life and microgravity research on the ISS. During the first of two study phases, the study task group conducted an assessment of (1) the readiness of the U.S. scientific community to use the ISS for life and microgravity research and (2) the relative costs and benefits of either dedicating an annual space shuttle mission to life and microgravity research during assembly of the ISS or maintaining the current schedule for ISS assembly in place.

The study has focused on the research areas that would utilize the pressurized laboratories in the International Space Station. These areas were considered from the perspective of both academic and industrial researchers.

At the request of Congress the study was conducted jointly with NAPA, as noted above. The NRC focused on scientific and technical aspects of the study, and NAPA focused on resource and cost-benefit assessments. During the phase-1 study, the two organizations worked in parallel while coordinating closely. This coordination included joint planning for the study and agreement on allocation of responsibilities at the beginning of the project, NAPA representation at all task group meetings, regular communication during the fact-finding stages, general agreement on the principal conclusions, and development of separate reports that would be published in a single document. The NAPA assessment, which was reviewed by NAPA and was not subject to the review process of the NRC, is included as an independent document in Appendix A of this report.

The Space Studies Board established the ad hoc Task Group on Research on the International Space Station with members having expertise in the areas of space life sciences and microgravity physical sciences. The task group held the first of two meetings for the phase-1 study in April 2001.

This document constitutes an interim report with findings from phase 1. During phase 2, and building on information collected during phase 1, the task group will address current and projected factors limiting the research utility of the ISS and will develop recommendations for improving the research community's ability to maximize the research potential of the ISS.

Information for this study was collected from NASA briefings to the task group, interviews with representatives of the scientific user community for the International Space Station, the cost-benefit assessment developed by the National Academy of Public Administration, and NASA documents available online. NASA also provided extensive data on its flight and ground research programs in response to detailed question lists developed by the task group.

Acknowledgment of Reviewers

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

Francois Abboud, University of Iowa,
John Buckmaster, University of Illinois,
Susan Doll, Harvard University,
Joel Koplik, City University of New York,
Gideon Rodan, Merck Research Laboratory,
Thomas Steitz, Yale University, and
Kathleen Taylor, General Motors Research and Development Center.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Mary J. Osborn, University of Connecticut. Appointed by the National Research Council's Report Review Committee, she was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring task group and the institution.

Contents

Executive Summary

The International Space Station has been officially under development by NASA since the late 1980s. Numerous changes in schedule and cost projections throughout the 1990s have prompted reevaluations of the number and scale of the major facilities that would eventually be placed on board; the schedule for developing, deploying, and utilizing those facilities; and the critical resources such as crew time and power needed to support ISS science research. As a result, specific concerns over schedule delays and potential downgrading of the ISS research capabilities have been growing for several years in the scientific community. In the fall of 2000, Congress directed the National Research Council (NRC) and the National Academy of Public Administration (NAPA) to organize a joint study of the status of microgravity research in the life and physical sciences as it relates to the International Space Station (ISS). The study is being conducted in two phases. This phase-1 report addresses the question of the scientific community's readiness to use the ISS for life and physical sciences and assesses the relative costs and benefits of dedicating an annual space shuttle mission to research versus simply maintaining the current schedule for assembly of the ISS.

RECENT CHANGES TO ISS SCIENCE CAPABILITIES

Subsequent to the initiation of this study, NASA announced large cost overruns for the construction of the ISS (Goldin, 2001). As a consequence, major changes were proposed by the agency in the ISS design that would reduce the total ISS crew capacity from six or seven to three, and cancel or delay indefinitely the development and deployment of many of the planned major research facilities. To accommodate both the possibility of a rescoped station and the uncertainty regarding the actual extent of such a rescoping, the Task Group on Research on the International Space Station chose to consider two alternate scenarios in developing its conclusions. In the first scenario the task group assumed that the August 2000 design for the ISS,[1] designated "Rev. F" by NASA,[2] remains unchanged. Under Rev. F, the ISS would support a full crew of six to seven astronauts and provide fully instrumented, dedicated facilities for research in a range of science disciplines. In the second scenario the task group assumed that the design and schedule changes contained in the proposed fiscal year (FY) 2002 budget for NASA are implemented. The proposed changes would result in a three-person crew and deletion or indefinite delay

[1]Still the official design at press time.
[2]ISS Rev. F Assembly Sequence (8/00).

of a large number of research facilities, supporting hardware, and experiment modules. For convenience, this scenario is referred to as “proposed Rev. G” in this report.[3]

READINESS TO UTILIZE THE INTERNATIONAL SPACE STATION

The task group was extremely concerned about the schedules for the development and deployment of ISS research facilities that were presented by NASA during the course of this study. In the task group’s view, a fully equipped ISS—including adequate crew support, electrical power, and experiment accommodations—needs to be in operation if NASA’s scientific objectives are to be achieved. Proposed reductions in crew size, facilities, and power have caused great concern in the scientific community. Specific concerns expressed by groups representing the ISS user community (Sekerka, 2001; Fettman, 2001; Katovich, 2001) have strengthened this task group’s view that the future of science on the ISS would be severely impaired under the proposed Rev. G scenario.

Based on a review of NASA’s program data—including ISS experiments planned, rates of proposal submission, and success and student funding levels—as well as input from members of the ISS user community, the task group reached the following conclusions:

- The U.S. scientific community is ready now to use the ISS.
- However, this readiness cannot be sustained if:
  –The proposed reductions in the scientific capabilities of ISS take effect, or
  –Slippage continues in both the development and science utilization schedules for the ISS as currently proposed, or
  –Uncertainties continue in funding for science facilities and flight experiments on the ISS.

Adding Annual Shuttle Missions for Laboratory Science

Proposed reductions in available experiment accommodations, crew, and power raise concerns about the ultimate functionality of ISS and thus directly affected the task group’s consideration of whether additional shuttle flights dedicated to science should be flown during ISS assembly and outfitting.

The task group concluded that ISS science could not proceed without the appropriate crew support and a clearly defined time line for deployment and completion. If the present Rev. F design and schedule were maintained, then it would be preferable to proceed with construction of a fully equipped ISS rather than divert resources to fly ISS science on additional shuttle missions. However, if ISS capabilities were to be reduced below Rev. F levels and there were no annual microgravity research-dedicated shuttle flights, then the viability of the overall program in microgravity research would be seriously jeopardized, as would the ability of NASA to achieve its stated scientific goals for the ISS. Therefore, if it becomes apparent that the ISS will not be available for meaningful microgravity research by the beginning of FY 2006, then annual shuttle flights dedicated to microgravity experiments should be made a part of the program.

Specifically, the task group recommends that:

A. Assuming that the Rev. F schedule and capability are achieved, then:
   1. If ISS development were to be the funding source for additional microgravity shuttle flights, then no additional shuttle flights should be planned for microgravity research.

---

[3]Though based on NASA’s draft Rev. G Assembly Sequence (4/01), this scenario is currently referred to by NASA as the 2002 Presidential Budget Submission.

2. If funding were to be provided from new sources, then it would be highly beneficial to fly additional annual flights until the ISS (with Rev. F capabilities) is complete.

B. Assuming that the proposed Rev. G schedule and capability are selected, then:

1. If capabilities were to be reduced according to Rev. G projections, then annual shuttle flights devoted to science should be flown until the ISS reaches either the research capability planned for "assembly complete" under Rev. F, or a similar level of capability that has been reviewed and approved by an independent body of scientists that can credibly represent the interests of the ISS user community.

In case B above, it should be noted that plans to use the shuttle will have to be integrated into the overall NASA mission planning by 2004. These recommendations also assume that the currently planned space shuttle microgravity missions, STS-107 and STS-123 (R2), planned for 2002 and 2004 respectively, are conducted as scheduled. Also, the activities described above should not be accomplished in such a manner as to jeopardize the sustainability and readiness of the program for microgravity research in the biological and physical sciences.

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1

Introduction

BACKGROUND

Laboratory Research in Space

NASA's Office of Biological and Physical Research[1] funds research that is concerned with the effects of reduced gravity on physical, chemical, and biological phenomena. The various phenomena studied, on which gravity can have a profound effect, range from smoldering combustion to bone loss in humans. The goal of such research is generally to use reduced gravity as a tool to gain a better understanding of these fundamental phenomena, many of which are also important to a range of industrial processes. Such knowledge not only contributes to several fields of basic science, but is also needed to enable the development of countermeasures for microgravity-induced changes in astronaut physiology as well as improved spaceflight technologies. Given that it is not practical in this brief report to describe the various areas of research, the reader is referred instead to previous NRC reports (NRC, 1995, 1998, 2000) that detail the research and accomplishments in the discipline programs and recommend specific research priorities.

In the absence of a permanent laboratory in orbit, there are basically four ways to carry microgravity life and physical sciences investigations into space. There are mid-deck lockers in the crew cabin of the shuttle, but their volume is small[2] and they are severely limited in number for any particular flight. Until 1998 there was the Spacelab module, which provided significant volume, power, crew access, and standard lab facilities for longer experiments. In addition, there is the commercial SPACEHAB facility, which provides a research volume between the volumes of the first and second options. And finally, there are free-flyers (essentially unmanned satellites launched into a temporary orbit lasting days to months), which are limited to carrying fully automated experiments. Unlike the first three methods, however, free-flyers do not permit research studies that rely on the use of human subjects and/or require crew intervention to conduct the investigations.

Successfully completing a mission to support a group of scientific investigations requires a long period of preparation in advance of the flight, adequate research funds, flight-qualified research hardware, and a well-trained crew to perform in-flight research activities. Flight opportunities are also limited by competition for shuttle manifest slots for other purposes, most notably flights to support the assembly,

[1]Formerly the Office of Life and Microgravity Sciences and Applications.
[2]$10 \times 17 \times 20$ inches of interior volume.

outfitting, and maintenance of the International Space Station (ISS) itself. Consequently, when considering whether to add non-ISS flight opportunities, NASA must weigh the benefits of providing continuing flight research opportunities to nurture, develop, and sustain a research community that will be ready to use the ISS against the benefits of completing the assembly of the ISS on schedule and within budget.

The International Space Station

The space station has been officially under development by NASA since the late 1980s. During that time, the scope of the effort has been reevaluated, resized, and redistributed several times, with perhaps the largest rescoping of the design occurring in 1992-1993. At that time NASA distributed some of its costs and development responsibilities among several international partners in exchange for research time and resources aboard the ISS. As a result of changes in both the design of the ISS and its schedule for development, it has been necessary for NASA to reexamine repeatedly the station's ability to support its promised goal of "world-class research" in both the biological and physical sciences. NASA noted as follows in "International Space Station Familiarization: Mission Operations Directorate Space-Flight Training Division," July 31, 1998, available on its Web site:

> The purpose of the ISS is to provide an earth orbiting facility that houses experiment payloads, distributes resource utilities, and supports permanent human habitation for conducting research and science experiments in a microgravity environment (ISSA IDR no. 1, Reference Guide, March 29, 1995). This overall purpose leads directly into the following specific objectives of the ISS program:
>
> - Develop a world-class orbiting laboratory for conducting high-value scientific research.
> - Provide access to microgravity resources as early as possible in the assembly sequence.
> - Develop effective international cooperation.
> - Provide a testbed for developing 21st Century technology.

The changes in schedule and cost projections throughout the 1990s have prompted reevaluations of the number and scale of the major facilities that would eventually be placed on board; the schedule for developing, deploying, and utilizing those facilities; and the critical resources such as crew time and electrical power needed to support ISS science research.

Specific concerns over schedule delays and potential downgrading of ISS research capabilities have been growing for several years in the scientific community (Sigler et al., 2000) and have been cited in a number of NRC reports reviewing space laboratory sciences (NRC, 1992, 1997, 1998). More recently, internal scientific committees that advise NASA at various organizational levels have voiced considerable alarm at the possibility of further reductions in ISS science support capabilities (Sekerka, 2001; Fettman, 2001; Katovich, 2001). In the fall of 2000, Congress directed that the National Research Council and the National Academy of Public Administration (NAPA) should organize a joint study of the status of microgravity research in the life and physical sciences as it relates to the ISS. As detailed in the preface, the study is being conducted in two phases. For this phase-1 report, the NRC was asked to address the questions of the state of readiness of the scientific community to use the ISS for life and physical sciences, and to work with NAPA on an assessment of the relative costs and benefits of dedicating a yearly space shuttle mission for research versus simply maintaining the current schedule for assembly of the ISS.

TABLE 1.1 Comparison of Research Support Capabilities for Rev. F and Proposed Rev. G

Research Support Capability	Rev. F	Proposed Rev. G
Number of crew[a]	6 to 7	3
Total power	110 kW[b]	73 kW[c]
Rack volume for research[d,e,f]	34.4 m^3	20 m^3
Number of research racks[d]	27	18[g,h]

NOTE: Data taken from various NASA briefings.
[a]NASA currently estimates a minimum of 2.5 crew required for maintaining the ISS, exclusive of any science-related duties.
[b]Forty-five kilowatts would be available for research.
[c]Obtained by subtracting the power provided by the Starboard Photovoltaic Array deleted in NASA's Rev. G Assembly Sequence. As this report was going to press, there were indications that the array might be reinstated.
[d]U.S. share.
[e]Numbers based on NASA estimates of 0.5 m^3 of research volume for each EXPRESS rack and 1.6 m^3 of research volume for international standard payload racks (ISPRs). EXPRESS rack volume is less than in ISPRs due to volume used by mid-deck locker hardware.
[f]Both volumes are reduced if ISPRs for freezers and the window observation facility are discounted.
[g]Racks eliminated are the habitat holding rack 2, fluids and combustion facility 2, fluids and combustion facility 3, materials science research facility 2, materials science research facility 3, commercial materials, biotechnology facility, x-ray diffraction system, and advanced human support technology.
[h]Note that the table does not include data on the experiment modules also eliminated in proposed Rev. G.

Subsequent to the initiation of this study, NASA announced large projected cost overruns in the construction of the ISS. As a consequence, major changes were proposed in the most recent official ISS design, which NASA refers to as Rev. F,[3] that would reduce the total ISS crew capacity from six or seven to three, reduce the station's electrical power, and cancel or delay indefinitely the development and deployment of many of the planned major research facilities. (Table 1.1 compares Rev. F with the restructured ISS, called "proposed Rev. G"[4] in this report.) The likely impact of these changes on the ability of the ISS to support science research would be severe. It was necessary, therefore, for the task group to make adjustments during the course of the study to accommodate both the possibility of a rescoped station and the uncertainty regarding the extent of such a rescoping. In the chapters that follow, this report outlines both the approach taken by the task group to deal with these uncertainties and the conclusions it developed.

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[3]ISS Rev. F Assembly Sequence (8/00).
[4]Though originally based on NASA's draft Rev. G assembly sequence (4/01), this scenario is currently referred to by NASA as the 2002 Presidential Budget Submission.

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2

Readiness to Utilize the International Space Station

READINESS OF THE CURRENT SCIENCE COMMUNITY

The first charge to the task group carrying out this study was to "conduct an assessment of the readiness of the U.S. scientific community to use the ISS for life and microgravity research. . . ." The task group defined "readiness" from the perspective of the principal investigator (PI).[1] That is, it asked, is the PI ready, willing, and able to utilize the ISS when it is completed with the scientific capabilities commensurate with the needs of the research program in biological and physical sciences? There are various components of readiness for the scientific community, including the intellectual preparedness of both established PIs and young investigators, experimental paradigms that have undergone preliminary evaluation in ground-based research, and a queue of well-conceived and feasible experiments that require the longer-term exposure to microgravity offered by the ISS.

The readiness of the scientific community was evaluated on the basis of program information provided in briefings by NASA personnel, written answers from NASA in response to questions developed by the task group, and informal interviews of the chairs of the Discipline Working Groups (advisory committees of academic and industrial scientists who represent the interests of the research communities that utilize NASA's microgravity research platforms). The program information reviewed by the task group included data on proposals submitted and funded under various NASA Research Announcements since 1996, current and estimated future levels of grant funding, the date of the last experiment flown in each discipline, estimated numbers of scientific and commercial investigations in each discipline that will be flown in the next several years, and funding levels for student programs.

The task group confirmed that there is a cadre of scientists capable of carrying out flight experiments in all the disciplines examined; most of these individuals have been supported in part by NASA for a number of years. In FY 2001 about 990 investigations are being funded by NASA's Office of Biological and Physical Research (OBPR), with some 18 percent of them in the flight program and the rest currently in the ground-based program. The total level of funding for these grants is approximately \$154 million.[2] Many disciplines have recruited high-quality investigators into the program and have an active, albeit small, graduate student group participating in these planned experiments. A larger group of graduate students and postgraduate fellows are involved in ground-based microgravity research. For

[1]Each experiment selected for flight was originally proposed by an investigator who is responsible for its development and the analysis of its results.
[2]This number does not include flight hardware development costs.

instance, in the life sciences alone, more than 580 graduate students and postdoctoral associates were receiving some level of support through OBPR grants in FY 2000.

Evidence of significant contributions from investigators in many areas of research in the microgravity environment was noted. The contributions included a more fundamental understanding of convection and solidification, diffusion processes and liquid-phase sintering, critical differences in fire sensing and control in microgravity, and development of tissue-engineered artificial bone and cartilage matrices. In FY 2000 alone there were over 1600 articles printed in peer reviewed publications by OBPR-funded investigators and another 174 books or book chapters[3] based on OBPR-funded work. Future research that could be optimally performed on the ISS includes experiments from all disciplines. A few examples (noninclusive) are as follows:

- Effect of long-term exposure to microgravity on various aspects of physiology and human behavior—for example,
  - –Bone and muscle loss and evaluation of therapies to prevent these losses;
  - –Immunological responses in animals and humans;
  - –Development of the vestibular system in animal models such as rodents; and
  - –Neurovestibular function and development.
- Studies on the effects of microgravity on physical phenomena, such as the following:
  - –Extension of the study of critical-point phenomena;
  - –Study of interfacial dynamics affecting crystal growth and liquid-phase sintering; and
  - –Determination of fundamental limits and parameters of combustion phenomena, as well as development and validation of techniques for fire sensing and control in microgravity.

Readiness is also attested to by the long list of experiments that have already been peer reviewed and approved for flight. In recent years the overall success rate of research proposals submitted to OBPR has averaged about 20 percent, with about one in seven of the successful proposals selected for the flight program. As shown in Tables 2.1, 2.2, and 2.3, there is a sizable group of selected flight experiments in all disciplines for ISS. There was general agreement across disciplines that there are fundamental scientific insights to be gained by doing these experiments in the prolonged microgravity environment on the ISS. In addition to allowing assessment of potentially cumulative effects of exposure to microgravity, this environment would also allow iterative modifications of experimental parameters in an efficient and timely manner.

[3]According to the FY 2000 Life Sciences Program Tasks and Bibliography and the Physical Sciences Research Division Program Tasks and Bibliography, NASA, Washington, D.C.

TABLE 2.1 Flight Investigations Plan for Physical Sciences

	Planned Flight Investigations to Orbit						
Discipline	FY01	FY02	FY03	FY04	FY05	FY06	Total No. of Selected Flight Research Investigations Currently in the Program[a]
Fluid physics	1	1	1	2	5	8	33
Combustion science	1	2	0	2	2	5	16
Materials science	0	1	1	4	10	13	19
Biotechnology	9	15	18	15	18	12	6
Fundamental physics	0	0	0	0	1	4	12

NOTE: Flight experiments are approved through a peer review process that includes consideration of the need for flight.
[a]As flight investigations mature and pass their science concept review, they are assigned to a flight opportunity. Flight opportunities depend on funding, hardware, and mission availability.
SOURCE: NASA.

TABLE 2.2 Flight Investigations Plan for Biomedical Research and Countermeasures

	FY01	FY02	FY03	FY04	FY05	FY06	Total Flight Projects in Program[a]
Total selected for flight	0	11	6	4	0	0	
Physiology		6	1	1			21
Behavior and performance		2	3	1			3
Radiation/environmental health		2	1	1			4
Clinical and operational medicine		1	1	1			8

NOTE: Includes ISLSWG experiments under NASA management. Experiments conducted over several years are counted in each year. NASA Research Announcement to be released in May 2001 will target research in musculoskeletal physiology, behavior and performance, and clinical/operational medicine; will be flown in the 2004-2006 time frame. Flight experiments are approved through a peer review process that includes consideration of the need for flight.
[a]Data in this column taken from Life Sciences Program Tasks and Bibliography for FY 2000.
SOURCE: NASA.

TABLE 2.3 Flight Investigations Plan for Fundamental Space Biology

	FY01	FY02	FY03[a]	FY04[a]	FY05[a]	FY06[a]	Total Flight Projects in Program[b]
Total selected for flight	2	6	4	1			
Molecular structure and physical interactions							
Cellular and molecular biology		1	2	1			11
Developmental biology	2	1	1				11
Organismal and comparative biology		4	1				11
Gravitational ecology[c]							
Evolutionary biology[d]							

NOTE: Flight experiments are approved through a peer review process that includes consideration of the need for flight.
[a]Solicitation for experiments in this time frame released May 2001.
[b]Data in column taken from Life Sciences Program Tasks and Bibliography for FY 2000.
[c]Area not listed separately in Life Sciences Program Tasks and Bibliography for FY 2000.
[d]Not solicited for flight.
SOURCE: NASA.

SUSTAINABILITY OF READINESS

The current readiness of the scientific community to utilize the ISS, as discussed above, does not ensure readiness when the ISS is finally assembled and outfitted for scientific research. Based on the task group's own experience with OBPR research programs and numerous discussions with members of the research community, it is the task group's observation that readiness is beginning to deteriorate, and that it will continue to erode with further delays in the date of completion for the ISS. This is an opinion widely shared in the ISS user community (Sekerka, 2001; Fettman, 2001).

Sustaining readiness, which is necessary to ensure full utilization of the scientific capabilities of the ISS, requires:

- Stable and adequate funding in each scientific area;
- Consistent and continued support of ground-based research;
- Regularly scheduled, reliable flight opportunities in the period leading up to availability of the ISS; and
- Confidence that the ISS with full research capability (as in Rev. F) will be available for experiments by the end of the decade.

Stable and adequate funding is necessary to retain the participation of top-level scientists in planning and research activities. If this does not occur they will abandon NASA for other research opportunities. In fact, some investigators stated that due to the inconsistency and uncertainty in the NASA science program, they have already reduced their participation to a part-time, hobby-like level. They have focused their research in other areas in order to maintain scientific credibility and career viability. Stable support is also required so that young investigators and graduate students consider space-based research a viable career opportunity. If ISS budgetary problems force new cuts in research funding, the cuts would have a major impact on the overall science program and would be a huge disincentive for the future involvement of many researchers. It would become even harder to attract to the field new investigators, who provide the sustaining expertise for the microgravity program and without whom the program, and therefore the ISS, will have little or no scientific future or value.

A strong ground-based research program provides the foundation for defining new concepts and developing techniques and for competitive selection of those experiments best suited for flight. Consistent and continued support for ground-based research is required at a level that ensures that the best science will be ready for flight and that new PIs and projects enter the program. NASA data show a ratio of about five ground investigations for every flight investigation. The task group's assessment is that this is the minimum ratio required to sustain a high-quality research program.

Scheduled and reliable flight opportunities provide investigators with continuity in their research activities and enable them to allocate resources and maintain interest through consistent progress in space-based research. Disruptions in these schedules increase the costs that must be borne by the research program, thereby limiting new research opportunities. For example, for microgravity research shuttle flight STS-107, originally scheduled to occur in late 1999, the SPACEHAB carrier lease delay penalty cost due to the launch slip to April 2002 has been $25.5 million, or $1.5 million per month (see NAPA report in Appendix A). Flight experiments also need to be carried out in a timely manner. If there are significant delays in flight opportunities, then the new techniques and equipment that become available for ground-based research will have to be evaluated and flight-qualified if they are to be used in space. It has taken many years to establish a competitively reviewed, science-based program with the participation of leading researchers who have identified critical problems and experiments. Delays in flight opportunities are already causing these researchers to reduce their commitment to space-based research. Further delays will exacerbate the situation, causing many investigators to abandon space research entirely. Were this to occur, it would take years to recover to even the present state. While relatively little detailed information is available on potential commercial users for ISS research capabilities, it is expected that long and uncertain delays in flight opportunities would also present serious impediments to industry research.

In 1998 the Committee on Space Biology and Medicine (NRC, 1998, p. 241) stated as follows:

> Issues relating to the design and utilization of the ISS are a major concern . . . . Repeated changes in the design of the ISS and the diversion of funds intended for scientific facilities and equipment into construction budgets have provoked alarm among the life sciences user community. Construction of the variable force centrifuge, essential for controlled life sciences experiments, has been substantially delayed [and cost overruns and delays seem likely for other research facilities]. . . . Issues relating to the adequacy of power, data transmission to and from Earth, and availability of crew time for research are also matters of significant concern.

The task group confirmed that the interest and participation of the scientific community are being adversely affected as the ISS continues to lose planned microgravity research capabilities (as dramatically illustrated by the proposed Rev. G facility delivery plan, shown in Figure 2.1 and Table 2.4). Industry investigators would be expected to have similar concerns regarding ISS capabilities. If a credible scientific program is to be realized, it is crucial to have confidence that the ISS, as originally planned and based on carefully assessed need, will be available for experiments. Experiments require adequate facilities, crew time, and electrical power. The proposed downsizing of the ISS (specifically, the elimination of the habitation module and the solar array, and the downsizing of the return vehicle) will substantially affect its ability to perform scientific research. NASA estimates that at least 2.5 crew members are required to maintain and operate the ISS exclusive of any science-related duties. Reducing the crew from six to three, as recently proposed, will severely limit the nature and extent of experiments that can be performed aboard the ISS, because many experiments require a substantial level of human participation as operators or subjects or both. This potential reduction in capability in and of itself would deal a crippling blow to NASA's stated goal of creating a world-class laboratory in space. The proposed elimination of a solar array (producing 37 kW) will significantly reduce the power available for experiments, complicating the conduct of simultaneous experiments and perhaps precluding experiments requiring high power levels (e.g., furnace-based experiments and those involving the centrifuge). The variable-force centrifuge continues to be essential for controlled life sciences experiments; its indefinite delay or elimination would seriously hinder scientific studies in areas such as fundamental biology.

The task group recognizes that as NASA finalizes its plans for the ISS in response to its latest budget difficulties, there will be a need to determine which projects in the flight queue are still viable. The impact of such decisions is unclear, as NASA was unable to give the task group the relative research priorities across scientific disciplines. The task group concludes that these priorities need to be immediately articulated, so that current restructuring of the ISS research program can be completed in a well-informed manner that is consistent with NASA's stated program goals.

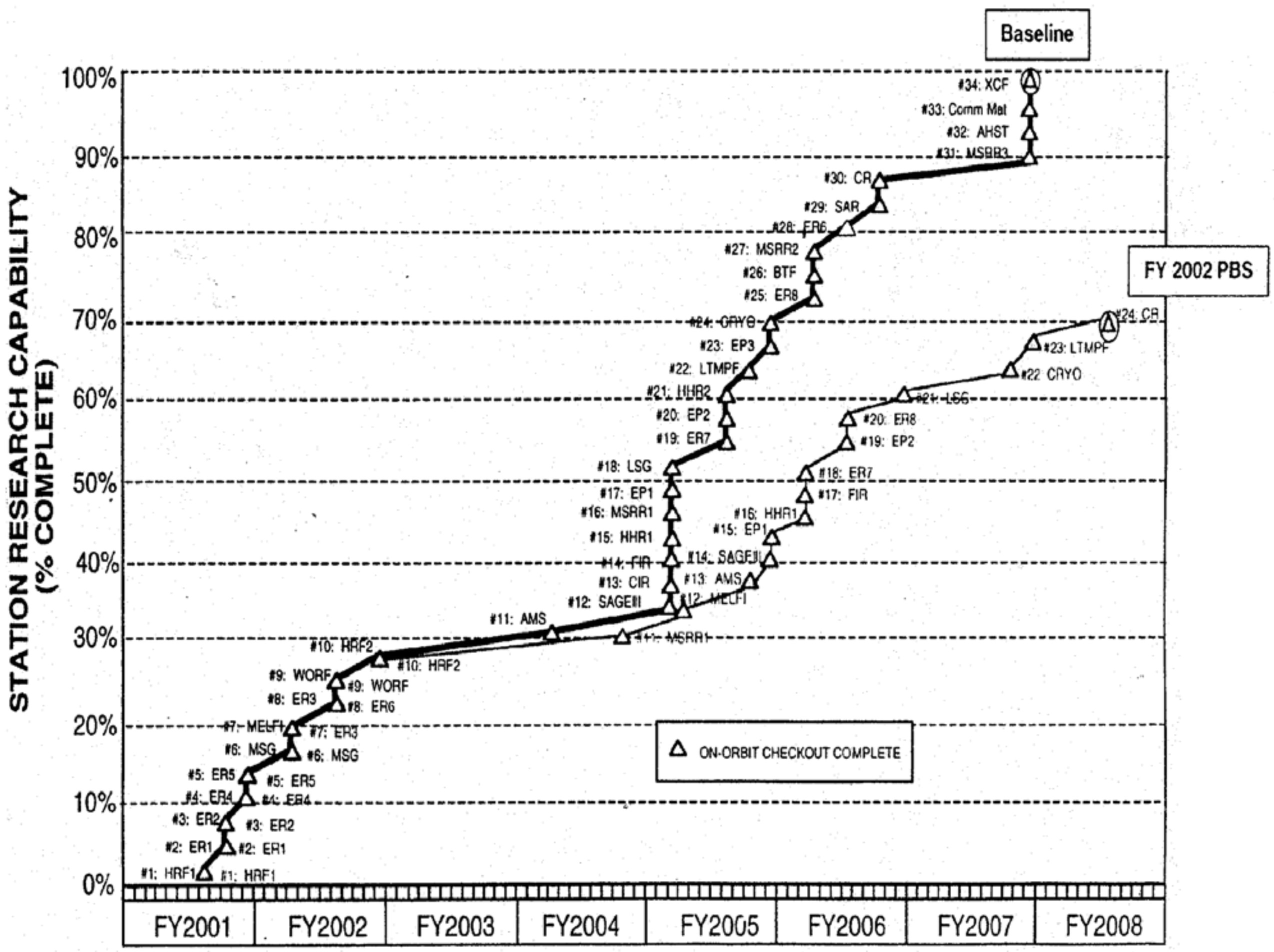

FIGURE 2.1 Change in delivery schedule for U.S. experiment facilities and support equipment between the baseline (Rev. F) and the FY 2002 PBS (proposed Rev. G). SOURCE: Kathie Olsen, Acting Associate Administrator, presentation at NASA Headquarters to the Biological and Physical Research Advisory Committee on June 14, 2001. See Appendix C for definitions of the acronyms appearing on the time lines.

TABLE 2.4 Rack Comparison Baseline (Rev. F) Versus FY 2002 PBS (Proposed Rev. G)

	Baseline, 27 Racks[a]	FY 2002 PBS, 18 Racks[b]
√[c]	Human research facility	Human research facility
√[c]	EXPRESS rack 1	EXPRESS rack 1
√[c]	EXPRESS rack 2	EXPRESS rack 2
	EXPRESS rack 3	EXPRESS rack 3
	EXPRESS rack 4	EXPRESS rack 4
	EXPRESS rack 5	EXPRESS rack 5
IP[d]	Microgravity science glovebox	Microgravity science glovebox
	Window observational facility	Window observational facility
	Human research facility 2	Human research facility 2
	EXPRESS rack 6	EXPRESS rack 6
	Habitat holding rack 1	Habitat holding rack 1
	Fluids and combustion facility 1	Fluids and combustion facility 1
IP[d]	Life sciences glovebox	Life sciences glovebox
	EXPRESS rack 7	EXPRESS rack 7
	Habitat holding rack 2	~~Habitat holding rack 2~~
	Fluids and combustion facility 2	~~Fluids and combustion facility 2~~
	EXPRESS rack 8	EXPRESS rack 8
	Fluids and combustion facility 3	~~Fluids and combustion facility 3~~
	Materials science research facility 2	~~Materials science research facility 2~~
	Materials science research facility 3	~~Materials science research facility 3~~
	Commercial materials	~~Commercial materials~~
	Biotechnology facility	~~Biotechnology facility~~
	X-ray diffraction system	~~X-ray diffraction system~~
	Advanced human support technology	~~Advanced human support technology~~
IP[d]	Minus-eighty-degree freezer	Minus-eighty-degree freezer
IP[d]	Cryo-freezer	Cryo-freezer

[a]Based on Rev. F assembly sequence and 1/8/01 MPOM.
[b]Racks shown with a strike-out line are not in the current budget guidelines and would be eliminated under Proposed Rev. G. Note that the remaining fluids and combustion rack facility in the second column is actually a fluids research facility (fluids integrated rack).
[c]√ On-orbit.
[d]International partner (IP) provides rack (the materials science research facility is partially IP-provided).
SOURCE: Kathie Olsen, Acting Associate Administrator, presentation at NASA Headquarters to the Biological and Physical Research Advisory Committee on June 14, 2001.

CONCLUSION

Based on analyses of the available information, the task group concluded as follows:

- The U.S. scientific community is currently ready to use the ISS for life and microgravity research.
- However, a number of factors, particularly the reduction in crew size to three astronauts, appear to put the sustainability of this readiness in serious jeopardy.

REFERENCES

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3

Adding Annual Shuttle Missions for Laboratory Science

EFFECT OF ISS CHANGES ON TASK

The second charge to the task group in phase 1 of this study was as follows: "Complete an assessment of the relative costs and benefits of either dedicating an annual space shuttle mission to life and microgravity research during assembly of the ISS or maintaining the current schedule for ISS in place."

There were numerous factors that had to be taken into account by the task group and NAPA when considering a question as complex as this one. Because the configuration of the ISS was in a state of flux, the task group was not able to obtain firm estimates of the ISS's projected capabilities or their scheduled availability. Based on presentations from NASA personnel and other NASA materials, the task group selected two scenarios. The first envisioned configuration and capabilities as per Rev. F. The second envisioned a notable decrement in capability (proposed Rev. G). In considering both scenarios, the task group's intent was to bound the potential capabilities and provide a context in which operational recommendations could be made in a more informed manner.

Consequences of a Three-Person Crew

A number of issues are affected by the potential redesign scenarios. Several capabilities are pacing items. For instance, cancellation or delay of the crew return vehicle limits the crew size to three. This means that at best, the equivalent of half of one crew member would be available to conduct science, according to briefings by NASA. Such a limitation would severely affect the science that depends on crew member participation as operators, observers, or subjects. Examples include nearly every type of biomedical research planned for the ISS, including that needed for countermeasure development, the onboard analysis of protein crystals, most glovebox experiments, and any physical science experiment requiring sample preparation or postexperiment manipulation. If, as seems likely, maintenance of the ISS requires the full attention of the downsized crew of three, then the ISS becomes ineffective as a platform for laboratory research.

Consequences of Reduced ISS Research Capability

Loss, delay, or significant downscaling of the Centrifuge Accommodation Module would preclude the performance of critical, onboard control experiments, without which valid interpretation of life science microgravity data becomes tenuous at best. The proposed removal of a major solar array wing may result in a significant reduction in power available for microgravity research. Many of the facilities, such as the furnaces used by materials science experiments, would require large amounts of power, as would certain life science facilities such as the centrifuge.

In addition to the changes that would seriously affect, or even cripple, a wide range of science disciplines, a number of proposed changes would target individual research disciplines. Reduction in the number of racks for research—such as the proposed reduction[1] of the three-rack fluids and combustion facility to a single fluids rack, the cancellation of two of the three materials science racks as well as most of the experiment module inserts for the remaining rack, and elimination of the mammal, plant, and cell culturing habitats for the Centrifuge Module—would have a major detrimental impact on materials and fluids research and eliminate most combustion and fundamental biology research from the ISS (see Table 2.4 in Chapter 2 and Figure 3.1).

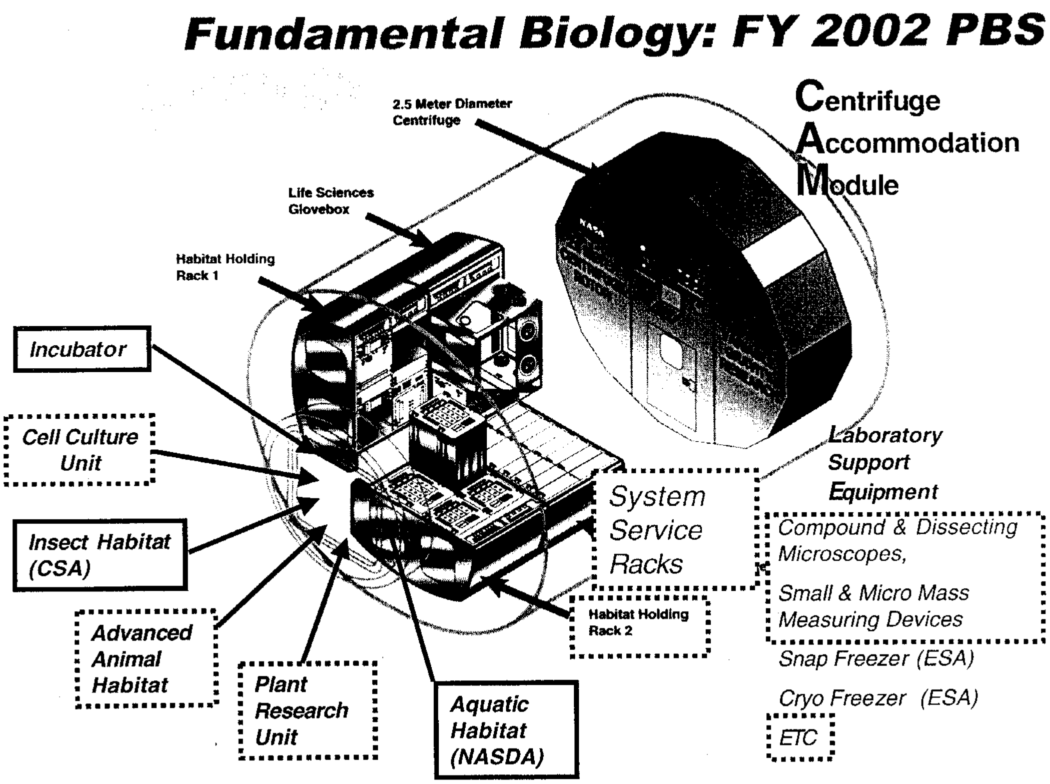

FIGURE 3.1 Habitat modules in the Centrifuge Accommodation Module that would be eliminated under proposed Rev. G. Dashed lines are drawn around the deleted habitats. SOURCE: Kathie Olsen, Acting Associate Administrator, presentation at NASA Headquarters to the Biological and Physical Research Advisory Committee on June 14, 2001.

[1]NASA's proposed FY 2002 budget.

COST-BENEFIT ANALYSIS OF ADDED SHUTTLE FLIGHTS

The cost-benefit issues of flying additional shuttle research missions are discussed in detail in the NAPA analysis performed for this study (see Appendix A) and are only summarized here. There are both financial and opportunity costs and there are benefits that are both subjective and tangible. In brief, the costs and benefits considered in the NAPA analysis fall into the following categories:

- Cost of mounting new microgravity research missions
    1. SPACEHAB lease costs (double research module);
    2. Selection, mission design, preparation, integration and testing, operations, deintegration and data analysis;
    3. Marginal cost of an added shuttle flight; and
    4. Cost impact of any ISS schedule slip as a result of diverting assembly funds.
- Benefit of maintaining ISS assembly without perturbing the schedule
    1. Avoidance of high-cost schedule slips;
    2. Likelihood of an earlier opportunity to begin ISS-based research;
    3. Less turmoil induced in the ISS program; and
    4. Focusing of all program activity on single target—outfitting and using the ISS.
- Benefit of adding shuttle research flights
    1. Ensures that at least some low-gravity research not requiring long-duration exposure is accomplished;
    2. Provides near-term opportunities for flight and scientific advancement;
    3. Enhances continuity of investigators in the biological and physical sciences program by providing near-term access to a microgravity environment;
    4. Sustains readiness by maintaining active participation of the investigator base;
    5. Demonstrates NASA commitment to support of microgravity activities; and
    6. Provides fire safety data in support of ISS outfitting.

Each of these points is analyzed in the NAPA report (Appendix A) and will not be repeated here. Utilizing the results of the NAPA analysis and its own evaluation, the task group came to conclusions on several questions relevant to this study.

Are Shuttle Flights Worthwhile?

Prior to the establishment of the ISS, microgravity research on the shuttle was substantial, in both physical sciences and biology. Many of the questions being posed for ISS flight could initially be addressed on the shuttle. Longer-term experiments (e.g., the effects of microgravity on the long-term growth of organisms) cannot be performed on the shuttle. The task group unanimously agreed that shuttle flights were worthwhile, but recognized the importance of longer-term experiments, which by their very nature would have to be performed on the ISS.

Is the Loss of High-Quality Microgravity Researchers a Pressing Issue?

To maintain high-quality microgravity research, a critical mass of investigators must exist in each field. The inability of researchers to attract graduate students and postdoctoral fellows for the study of microgravity has the potential to cascade into the total loss of that critical mass. If new students are not recruited now, there will be few faculty to recruit them later.

Will the Configuration Envisioned in Rev. G Be Capable of Conducting World-Class Microgravity Research?

In the absence of a crew return vehicle (critical in case of a disaster) and the habitation module, which would result in a lack of sufficient crew and crew time (now estimated as half a crew equivalent per week) to handle experiments, as well as the critically needed life sciences Centrifuge Accommodation Module, state-of-the-art experiments cannot be performed on the ISS (see Table 3.1 for a comparison of ISS with other platforms). If this occurs, more investigators will become convinced that there are no worthwhile opportunities in microgravity research. The end result will be a further decrease in the ability to recruit new students and a further diminution in the size of the community trained to do research in microgravity aboard the ISS.

TABLE 3.1 Comparison of Crew Availability for Various Space Laboratories

	Spacelab	Skylab	Mir	ISS
Crew	7 (4 dedicated to payload)	3	3	3
Percentage of crew available to work 8 hours a day on scientific activities	57	60 (estimate)	33 (estimate one crew member dedicated to payload)	16 (based on one half of one crew member's time available for payload activities)

CONCLUSIONS AND RECOMMENDATIONS

As previously discussed, there was not a defined scenario reflecting recently proposed budget constraints provided to the task group by NASA; hence, the task group bounded the problem with two alternative scenarios. These scenarios supplied a framework from which conclusions and recommendations could be made. In phase 2 of this report, the task group anticipates that sufficient information will be available to make more concrete recommendations. The two scenarios were based on Rev. F[2] and proposed Rev. G.[3]

Against this background, the task group makes the following recommendations:

A. Assuming that the Rev. F schedule and capability are achieved, then:
   1. If ISS development were to be the funding source for additional microgravity shuttle flights, then no additional shuttle flights should be planned for microgravity research.
   2. If funding were to be provided from new sources, then it would be highly beneficial to fly additional annual flights until the ISS (with Rev. F capabilities) is complete.

B. Assuming that the proposed Rev. G schedule and capability are selected, then:
   1. If capabilities were to be reduced according to Rev. G projections, then annual shuttle flights devoted to science should be flown until the ISS reaches either the research capability planned for "assembly complete" under Rev. F or a similar level of capability that has been reviewed and approved by an independent body of scientists that can credibly represent the interests of the ISS user community.

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[2]Rev. F Assembly Sequence (8/00).
[3]Based on draft Rev. G assembly sequence (4/01) as supplied by NASA to the task group and the 2002 Presidential Budget Submission.

The task group unanimously agreed that a fully equipped ISS as defined in Rev. F—including adequate crew support, electrical power, and experiment accommodations—is needed if NASA's stated scientific ISS goals are to be realized. If ISS capabilities were to be reduced (as in proposed Rev. G) and there were no annual shuttle flights dedicated to microgravity research, then the viability of the overall program of research in microgravity would be seriously jeopardized, as would be the ability of NASA to achieve its stated scientific goals for the ISS. If it becomes apparent that the ISS will not be available for microgravity research by the beginning of FY 2006, then annual shuttle flights dedicated to microgravity experiments should be made a part of the program. Beginning 2 years ahead, in FY 2004, plans to use the shuttle should be integrated into the overall NASA mission planning. These recommendations all assume that space shuttle microgravity missions STS-107 and STS-123 (R2), planned for 2002 and 2004, respectively, are conducted as scheduled. And, finally, the activities defined above should not be accomplished in a manner that would jeopardize the sustainability and readiness of the microgravity research program.

Appendixes

Appendix A

National Academy of Public Administration Phase 1 Report: Research on the International Space Station

Executive Summary

The U.S. microgravity research community is approaching a crisis. The schedule for International Space Station (ISS) assembly and readiness to support microgravity research is being significantly delayed. This will profoundly decrease the ability to conduct world-class research in the microgravity environment of space.

This report weighs the advantages and disadvantages of adding annual Space Shuttle flights dedicated to microgravity research to ensure the continued viability of the microgravity research community. Elements of the ISS critical for microgravity research are likely to be deleted due to lack of funds. Two Space Shuttle-based microgravity research flights are scheduled in 2002 and 2004. This leaves very limited flight opportunities until the ISS is fully ready to support microgravity research, a date which is rapidly receding. As a result, the U.S.'s premier microgravity researchers are looking elsewhere for the bulk of their research activities. New, young researchers avoid space research due to the dearth of near-term flight opportunities. Erosion of the space microgravity community has begun and is accelerating. Action is required if a viable research community is to be present when the full ISS microgravity research capability is in place.

The Phase 1 conclusions, basically agreed to by the members of the National Academy of Public Administration's (NAPA) study team and the National Research Council's (NRC) Task Group on Research on the International Space Station (TGRISS), were reached by examining two sets of assumptions and proposed actions.

Assembly Sequence F is the assembly plan under which NASA is currently operating in building the ISS. Assembly Sequence F provides the ISS with a robust complement of facilities and equipment for microgravity research, including a 6 or 7-person crew to support the research activities.

(A) Assuming Assembly Sequence F schedules and capabilities are achieved, then:

NOTE: The report in this appendix is reproduced as it was supplied by the National Academy of Public Administration. It was not reviewed or edited by the National Research Council.

1. If currently planned ISS development monies are to be the funding source for additional microgravity shuttle flights, then no additional shuttle flights should be planned for microgravity research.
2. If funding were to be provided from new sources, it would be highly beneficial to fly annual flights.

Assembly Sequence G is the NASA ISS assembly plan which responds to the direction by the Administration to help in solving current ISS funding issues. It is still in draft and has not been approved as yet by the appropriate authorities. Assembly Sequence G would result in a significant reduction in the microgravity research capability on the ISS, and the proposed three-person crew would severely limit the ability to conduct microgravity research aboard the ISS.

(B) Assuming Draft Assembly Sequence G schedule and reduced capability are implemented, then annual shuttle flights devoted to science should be flown until ISS reaches research capability planned for assembly complete under Sequence F.

Chapter 1 - Introduction

A. Statement of the task

This report is in response to Congressional direction specified in the Fiscal Year (FY) 2001 National Aeronautics and Space Administration (NASA) Authorization Bill – Section 203.

SEC. 203. RESEARCH ON INTERNATIONAL SPACE STATION.

(a) STUDY. – The Administrator shall enter into a contract with the National Research Council (NRC) and the National Academy of Public Administration (NAPA) to jointly conduct a study of the status of life and microgravity research as it relates to the International Space Station. The study shall include –

(1) an assessment of the United States scientific community's readiness to use the International Space Station for life and microgravity research;

(2) an assessment of the current and projected factors limiting the United States scientific community's ability to maximize the research potential of the International Space Station, including, but not limited to, the past and present availability of resources in the life and microgravity research accounts within the Office of Human Spaceflight and the Office of Life and Microgravity Sciences and Applications and the past, present and projected access to space of the scientific community; and

(3) recommendations for improving the United States scientific community's ability to maximize research potential of the International Space Stations including an assessment of the relative costs and benefits of –

(A) dedicating an annual mission of the Space Shuttle to life and microgravity research during the assembly of the International Space Station; and

(B) maintaining the schedule for assembly in place at the time of the enactment.

(b) REPORT. –Not later than 1 year after the date of the enactment of this Act, the Administrator shall transmit to the Committee on Science of the House of Representatives and the Committee on Commerce, Science, and Transportation of the Senate a report on the results of the study conducted under this section.

After discussions between the NRC and Congressional staff the direction delineated in the Authorization Bill was translated to the following study task statement.

> **This study will be organized on behalf of the NRC by the Committee on Space Biology and Medicine (CSBM) of the Space Studies Board and will be conducted over a 2-year period in two consecutive 12-month phases. During the first 12-month phase, the NRC and NAPA will complete an interim report that will assess the following:**
>
> **(1) the readiness of the United States scientific community (including the commercial research community) to use the ISS for life and microgravity research; and**
>
> **(2) the relative costs and benefits of**
>
> **(a) dedicating an annual mission of the Space Shuttle to life and microgravity research during assembly of the ISS versus**
>
> **(b) maintaining the schedule for assembly in place at the time that the study is initiated.**
>
> **During the second 12-month phase, the NRC and NAPA will address the following three issues:**
>
> **(1) assess the current and projected factors limiting the United States scientific community's ability to maximize the research potential of the ISS including but not limited to,**
>
> **(a) the past and present availability of resources in the life and microgravity ISS research utilization accounts with the Office of Space Flight;**
>
> **(b) the availability of resources (crew training time, crew on-orbit time, power, upmass, stowage, etc.) on the ISS during assembly and at assembly complete; and**
>
> **(c) the past, present, and projected access to space of the scientific community; and**
>
> **(2) provide recommendations for improving the United States scientific community's ability to maximize the research potential of the International Space Station.**

B. Methodology

The planning for the construction of the ISS is a very dynamic activity. Schedules, timelines, and even the elements comprising the ISS are in a continual state of change. Assembly Sequence F is the schedule currently in place. However, the changes directed by Administration will have a very substantial impact on both the assembly schedule and the complement of ISS hardware elements. Assembly Sequence G, currently in planning by NASA, is a major deviation from the assembly sequence that was in place at the start of the task. The NAPA study team made assumptions based upon assembly sequence schedules, ISS research hardware elements included/excluded and source of funds for added microgravity research flights aboard the Space Shuttle.

The feasibility of adding a microgravity research flight(s) was examined from both the microgravity research and Space Shuttle/ISS perspectives. This entailed assessing the impact to both funding and schedules.

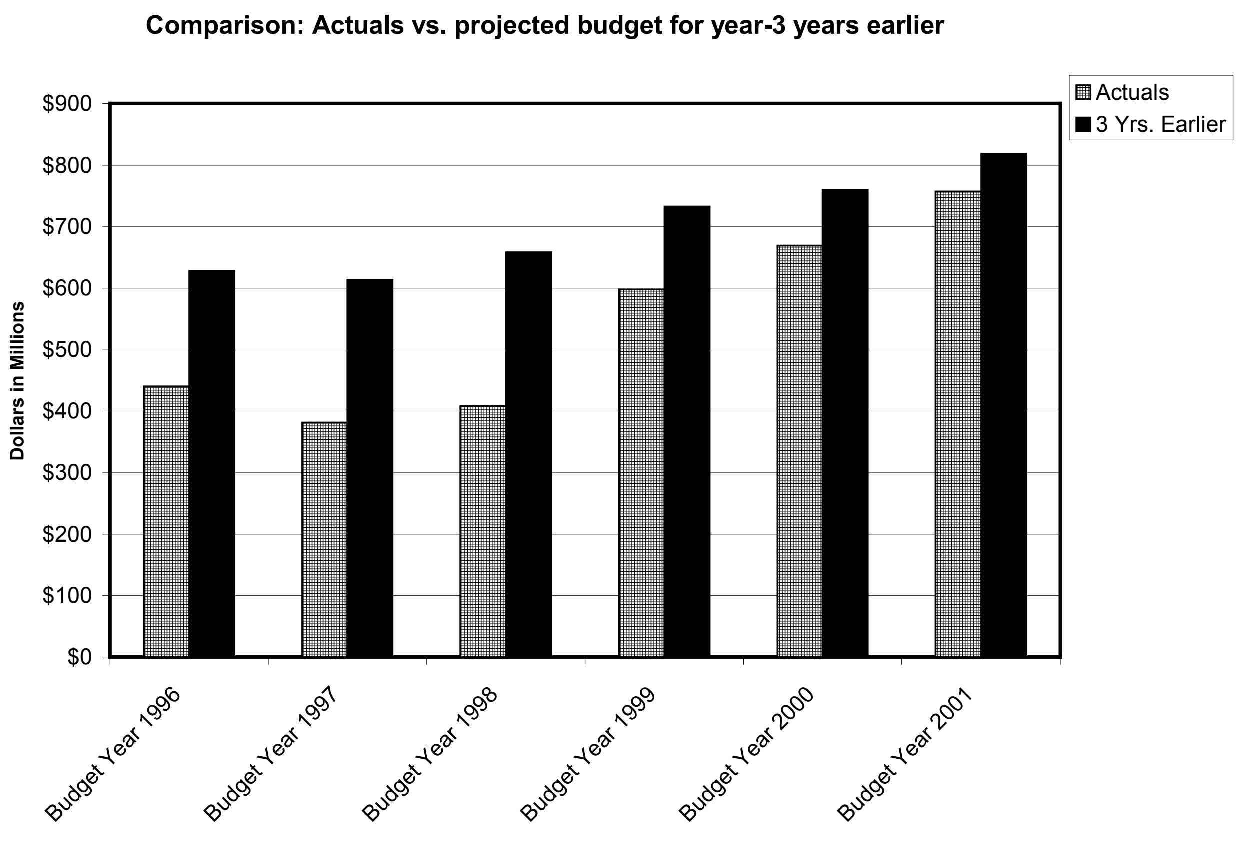
Chapter 2 – History

As shown in Chart 1, the Microgravity Program has been used by NASA as a "shock absorber" to reduce the budgetary impacts of development problems that resulted in schedule delays and cost overruns. A combination of the need to fund budget shortfalls in ISS budget requirements and delayed readiness of the

ISS to support microgravity research has reduced microgravity science flight activities from the expectations of a decade ago. The microgravity budget was reduced by about one-third from the expected funding in the budget projections made three years prior to the money actually being spent. This resulted in the loss of access to space for microgravity research as Space Shuttle flights were primarily dedicated to ISS assembly missions and the ISS itself was not yet available as a facility prepared to conduct microgravity research. With the loss of access to space, the funds for that part of the microgravity research program were diverted to the pressing needs of the ISS Program.

Chart 1 below provides a comparison between the expected funding for microgravity and what was actually provided three years later when that part of the program was funded.

[1]**Chart 1**



Chapter 3 – Space Shuttle Opportunities

Adjustments to the NASA budget by the Administration have resulted in a reduction from previously planned Space Shuttle flight rate levels. All of the lighter weight Space Shuttles are fully dedicated to ISS assembly flights, leaving only the heavier Columbia to support NASA's other space access requirements via the Space Shuttle. The flight rate changes currently under review by NASA, in response to Administration direction, have resulted in a net reduction of eight flights from the FY01 budget through FY 2004. Chart 2 delineates the changes by Fiscal Year (FY).

[1] Chart 1 derived from analysis of NASA's budget justification.

[2]Chart 2 -- Space Shuttle Flight Rate by Fiscal Year

	FY01	FY02	FY03	FY04	FY05	FY06	FY07
Per FY 2001 Plan	9	9	8	8	6	6	
Per FY 2002 Plan	7	7	6	6	6	6	6
Change	-2	-2	-2	-2			

The current Space Shuttle manifest shows two microgravity research flights. The first is STS-107, Research Mission Freestar, which is currently scheduled for launch on April 4, 2002 and the second is STS-123, Research Mission 2, scheduled for launch in May of 2004. The manifest also has a test flight of the Crew Return Vehicle (CRV) scheduled for February 2003. NASA is considering elimination of the CRV as part of the response to the Administration's funding targets. Deleting the CRV mission would free a launch slot, although significant hurdles to using that slot for an additional microgravity research mission remain, i.e., time and money. The February 2003 CRV launch date is too soon to permit a new research flight to fall into that launch slot. In all likelihood the fastest a new mission could be designed and readied for launch is approximately two years after approval.

This picture is further clouded by the uncertainty surrounding the date of complete ISS assembly. If Assembly Sequence F is assumed, that date is in 2006. If Assembly Sequence G is assumed, then the assembly completion now coincides with completion of the U.S. core in 2004. *This leaves only 2003 open as a year in which there is not a microgravity research flight during ISS assembly*. Given that there is little time between now and the end of 2003 to design, integrate and fly a new mission, the ability to add research flights during ISS assembly may be overtaken by events.

Chapter 4 – Cost and Impact of Adding Microgravity Mission(s)

A. Cost of undertaking a new microgravity research mission

Two NASA Offices within the Human Exploration and Development of Space (HEDS) Enterprise would be responsible for the marginal cost of an added Space Shuttle mission. NASA's Office of Space Flight (Code M) would fund the cost of an External Tank (ET), refurbishment of the Solid Rocket Boosters (SRB), mission planning and operations, payload Integration and Test (I&T) into the Shuttle. The other, the Office of Biological and Physical Research (Code U), would be responsible for the lease of the Spacehab, Inc. module (a non-Government leased facility) should NASA decide to use that structure for a new mission, as well as all costs associated with planning, operating and completing data analysis of the research mission payload.

The marginal cost of adding a new Space Shuttle mission is presented in Chart 3.

[2] Chart 2 is excerpted from Chief Financial Officer's budget back-up to NASA's FY2002 budget submission to the Congress.

[3]Chart 3
Space Shuttle Mission—Marginal Cost
$ in Million

		-3	-2	-1	launch year		total
Space Shuttle Program Office (SSPO)	0.0	0.0	0.8	1.4	29.9		32.1
Shuttle Flight Operations Center	0.0	0.0	0.8	1.4	29.4		31.6
Flight Ops				0.4	1.6		2.0
Ground Ops					9.7		9.7
Logistics					3.7		3.7
Program Integration			0.4	0.5	3.5		4.4
HW/SW Elements			0.4	0.5	3.7		4.6
Fee					7.2		7.2
FEPC					0.5		0.5
Kennedy Space Center (KSC)				2.0	6.6		8.6
KSC - Launch Operations					2.6		2.6
KSC - Payoad Integration to/from Shuttle				2.0	4.0		6.0
Marshall Space Flight Center (MSFC)		0.0	21.9	12.5	12.4	2.2	49.0
Space Shuttle Main Engine (SSME)					2.3		2.3
External Tank (ET)			7.2	7.0	4.7		18.9
Reuseable Solid Rocket Motor (RSRM)			14.7	3.3	2.6		20.6
Solid Rocket Booster (SRB)				2.2	2.8	2.2	7.2

NASA has two Space Shuttle borne microgravity research missions on the current manifest. They are STS-107 and STS-123. STS-107 was delayed from its original late 1999 launch date due to higher priority needs of the assembly of the ISS and is now scheduled for launch in April 2002. The delay has added significant Spacehab lease cost penalties as well as an increase to the associated cost of payload engineering support and principal investigator expenses.

Chart 4 provides a comparison of the projected total mission cost of the next two Space Shuttle microgravity research missions. As is evident, the expected cost for a mission is very consistent between the two missions, once the Spacehab lease delay penalties are removed from the projected cost of the STS-107 mission.

[3] Chart 3 was taken from data provided by NASA's Office of the Chief Financial Officer from data from the Office of Space Flight.

[4]Chart 4

New Obligation Authority (NOA) for next two STS microgravity Missions

Cost Source	STS-107	R2 Mission STS-123
Shuttle marginal costs	$88.7	$83.7
KSC payload processing	$5.0	$6.0
Payload engineering support	$22.5	$18.3
Principal Investigator costs	$11.0	**TBD**
Mission integration activities	$20.5	$30.4
Spacehab carrier lease delays through 8/01	$13.5	
Spacehab carrier lease delays 8/01 thru 4/02	$12.0	
TOTALS	**$173.2**	**$138.4**

Note: For STS-107 Spacehab launch slip cost = $1.5M per month.

Current budget is through an August 2001 launch date.

B. Source of funding for microgravity research mission(s)

Key to any discussion of the consequences of adding one or more Space Shuttle microgravity research missions is the source of the requisite funding. There are four scenarios for the source of needed funds, each with widely differing consequences.

> **(a) Congress augments the NASA budget with sufficient funds to cover the full-cost of the added research mission(s).** This option would have little effect on ISS assembly as NASA is currently staffed to support eight Shuttle launches per year while only six per year are planned. However, this scenario is very unlikely based on the past actions of the Congress. When NASA was last directed to add a microgravity research flight, the Congress provided only an additional $40M, well below the marginal cost of a research mission (approximately $150M).
>
> **(b) NASA assumes the full-cost of the added research mission(s) and taxes non-Human Exploration and Development of Space (HEDS) areas to obtain the required funds.** In this scenario the Administrator would decide which areas within the Agency, external to HEDS, would be affected. Since HEDS plus the fixed cost of Civil Service salaries accounts for more than half of NASA's annual budget, the impact of transferring funds would be shared among only half the budget. Since most of that money is committed against on-going projects, it would be the new work in non-HEDS areas (Space Science, Earth Science and Aeronautics) that would suffer inordinately.

[4] Chart 4 was created from data provided by NASA's Office of Biological and Physical Research (Microgravity research costs) and Office of Space Flight (Shuttle costs).

(c) NASA assumes the full-cost of the added research mission(s) and takes the funds from HEDS money currently earmarked for ISS assembly. The current budget can only support six Space Shuttle launches per year as indicated by the reductions shown in Chart 2. Adding any new mission(s) would result in a one-for-one reduction to the ISS assembly flight rate. This reduction would cause the ISS assembly timeline to stretch out. Given the monthly spending rate of the ISS Program, the effect would likely be an unacceptably high budget impact to the ISS program. Since it appears that the Administration is locking the annual cost of the ISS, such assembly delays would significantly impact the date when the ISS would be available for full microgravity research activities.

(d) NASA directs the microgravity program to fund additional mission(s). This option would have minimal effect on ISS assembly. There would be a cost due to extending the time for the assembly of the microgravity support elements (facilities and equipment). There would be a substantial cost to the microgravity research program, as that program would be asked to fund the entire cost of mounting additional Space Shuttle research missions. It would be penny wise and pound foolish to substitute two-week Space Shuttle missions at a cost of significant delays to the readiness of the ISS to conduct microgravity research. Since current plans may call for the deleting or reducing the capability of the Centrifuge Facility, any actions that further impact funds would only exacerbate the loss of microgravity research capabilities.

Only the first scenario, an augmentation to NASA's budget, results in minor changes to the Agency's current plans. However a thorough cost-benefit study should be undertaken by NASA to determine whether such additional funding is best used by the microgravity community for mounting short-term Space Shuttle missions or by accelerating the readiness date at which the ISS is ready for full-time research.

From Assembly Sequence E (dated June 1999) through Sequence F (dated August 2000) and continuing to the current Draft Assembly Sequence G, for some elements of the outfitting of the ISS for research, the delay has been as much as two years. The earlier outfitting activities, those originally scheduled to occur in 2000 and 2001 lost eight to nine months, while the activities scheduled in Sequence E to occur in 2003 and 2004 are now proposed to be done one and a half to two years later.

NASA has not yet finalized Draft Assembly Sequence G. In the likely event that Assembly Sequence G is initiated, very significant impacts to the microgravity research program would result. ISS microgravity facilities and equipment capabilities would be reduced. The proposal to limit crew size will affect the crew's ability to support research experiments. In addition the proposed loss of a major solar array would impact the amount of electrical power available for experiments. As directed in the task statement, Phase 2 of this report will assess the effects of these changes on ISS-borne microgravity research.

Chapter 5 – Microgravity Science Impacts

The long delay in ISS readiness to conduct microgravity research, combined with few opportunities for research flights aboard the Space Shuttle, has resulted in an erosion of enthusiasm within the microgravity science community. It should be remembered that when President Reagan made his initial speech proposing the Space Station in 1984, the operability date was 1992 – to celebrate the 500th anniversary of the landing of Columbus.

A. NASA's Office of Biological and Physical Research (Code U) selection process

The road from initial proposal to in-space microgravity research is a long and highly competitive process. Three competitive steps must be accomplished, with each step winnowing down the field of researchers.

(1) Ground Science Selection: Not all ground research proposals assume that a microgravity flight will be needed to achieve the desired information. When NASA releases requests for ground science proposals, peer review boards assess the relative merits of the submitted proposals. Receiving a NASA research grant is a very competitive process, with only a small percentage of submitted proposals gaining acceptance.

(2) Flight Science Selection: Those proposals requiring a microgravity environment in order to achieve their science objectives undergo further peer review to select and rank them. Those selected then proceed into development of the flight experiment and the requisite hardware, software and operational procedures. A ratio of between five and ten ground research proposals to each flight research proposal is preferred in order to assure the "best" science is available for a flight opportunity.

(3) Flight Assignment Selection: Of those proposals selected for "Flight Science," an assessment of priority for selection for a flight assignment is made. This results in a ready queue of experimenters awaiting an opportunity to fly, either on the Space Shuttle or the ISS. Unfortunately, because of the double hit of the ISS readiness date slipping and the sparse number of Shuttle-based microgravity research flights currently scheduled to occur during ISS assembly, the length of the queue far exceeds the opportunities for flight, the result being a high level of discouragement among the microgravity researchers.

The problem within the microgravity research community is that after investing years in competing in this process, the opportunities for conducting in-situ microgravity research are minimal.

B. Science benefits of assuring annual Shuttle microgravity research flights

The National Research Council's Task Group on Research on the International Space Station (TGRISS), as part of their research, interviewed representatives from each of the microgravity disciplines. The TGRISS group agreed that a serious problem is building in maintaining the high enthusiasm and interest of the most cutting-edge researchers participating in the NASA microgravity program. Researchers are looking at an ISS whose operational date has slipped two years during the past two years, while it is likely that its capabilities will be reduced significantly, perhaps to the point where microgravity research capability is totally compromised. At the same time, there are only two Shuttle-based microgravity research flights planned during the ISS assembly period – currently one in 2002 and one in 2004. Top researchers are looking toward other avenues for their research, as the opportunity for flight on a NASA vehicle fades. If NASA is to maintain a world-class microgravity program into the Space Station era, then it is imperative that the interest and enthusiasm of world-class researchers be nurtured and that they be afforded a reasonable opportunity to conduct their research in a timely manner. As was stated in the TGRISS Report of the National Research Council,

"There are many benefits to be derived from annual Shuttle-based microgravity research flights. The assurance that an annual research flight will occur reduces the impact of the late readiness of the ISS. Such annual flights:

1. Ensure that at least some microgravity research, that not requiring long-duration exposure, is accomplished,

2. Provide near-term opportunities for flight and scientific advancement,
3. Enhance continuity of investigators within microgravity by providing near-term access to a microgravity environment,
4. Sustain "readiness" by maintaining active participation of the investigator base,
5. Demonstrate NASA commitment to support microgravity activities, and,
6. Provide Shuttle-based gathering of fire safety information that will be needed in support of ISS outfitting."

Chapter 6 – Conclusions and Recommendations

The conclusions in this Phase 1 Report are based on NASA's Space Shuttle and ISS planning that is currently in a very high state of flux. NASA's response to the reluctance of both the Administration and the Congress to fund the latest ISS cost growth projections has not yet solidified. When these plans are firmly established, certainly in time to influence the findings and recommendations of Phase 2 of this report, the conclusions and recommendations currently held by the joint NRC/NAPA Task Group on Research on the International Space Station may well take a new direction. However, one thing is clear. The erosion of the microgravity research community has begun. It will accelerate if flight opportunities and research capabilities wane. Action is required if the nation is to maintain a strong, viable, world-class, microgravity space-based community.

The Phase 1 conclusions basically agreed to by the NRC and NAPA task group members examine a set of boundary conditions and propose action based upon each.

(A) Assuming Assembly Sequence F schedule and capability are achieved, then:

1. If ISS development monies were to be the funding source for additional microgravity shuttle flights, no additional shuttle flights should be planned for microgravity research.
2. If funding were to be provided from new sources, it would be highly beneficial to fly annual flights.

(B) Assuming Draft Assembly Sequence G schedule and reduced capability are implemented, then annual shuttle flights devoted to science should be flown until the ISS reaches research capability planned for assembly complete under Sequence F.

As stated throughout this report, there are many serious issues facing the ability to conduct microgravity research. The Task Group realizes that adding Shuttle flight(s) could have a negative impact on ISS assembly. However, if the ISS operability dates continue to slip, and microgravity research capability is reduced significantly, then Shuttle flights may well be the only opportunity for research in a microgravity environment for the better part of this decade. If the nation does not maintain its microgravity research community throughout the first part of this decade, it is entirely possible that when the ISS is finally ready the ability to conduct world-class research will not be there.

Appendix B

Excerpt from NASA Authorization Act of FY 2000

SEC. 208. RESEARCH ON INTERNATIONAL SPACE STATION.
(a) STUDY.–The Administrator shall enter into a contract with the National Research Council and the National Academy of Public Administration to jointly conduct a study of the status of life and microgravity research as it relates to the International Space Station. The study shall include–
(1) an assessment of the United States scientific community's readiness to use the International Space Station for life and microgravity research;
(2) an assessment of the current and projected factors limiting the United States scientific community's ability to maximize the research potential of the International Space Station,
including, but not limited to, the past and present availability of resources in the life and microgravity research accounts within the Office of Human Space Flight and the Office of Life and Microgravity Sciences and Applications and the past, present, and projected access to space of the scientific community; and
(3) recommendations for improving the United States scientific community's ability to maximize the research potential of the International Space Station, including an assessment of the
relative costs and benefits of–

(A) dedicating an annual mission of the Space Shuttle to life and microgravity research during assembly of the International Space Station; and
(B) maintaining the schedule for assembly in place at the time of the enactment.

(b) REPORT.–Not later than 1 year after the date of the enactment of this Act, the Administrator shall transmit to the Committee on Science of the House of Representatives and the Committee on Commerce, Science, and Transportation of the Senate a report on the results of the study conducted under this section.

Appendix C

Acronyms Used in Figures and Tables

AHST	Advanced Human Support Technology
AMS	Alpha Magnetic Spectrometer
APM	Attached Pressurized Module
BTF	Biotechnology Facility
CAM	Centrifuge Accommodation Module
CSA	Canadian Space Agency
EP	EXPRESS Pallet
ER	EXPRESS Rack
ESA	European Space Agency
FCF	Fluids and Combustion Facility
HHR	Habitat Holding Rack
HRF	Human Research Facility
INC	Increment
ISLSWG	International Space Life Sciences Working Group
ISS	International Space Station
JEM/PM	Japanese Experiment Module/Pressurized Module
JEM/EF	Japanese Experiment Module/Exposed Facility
LSG	Life Sciences Glovebox
LTMPF	Low-Temperature Microgravity Physics Facility
MELFI	Minus-Eighty-Degree Life Sciences Freezer
MLE	Mid-deck Locker Equivalent
MSG	Microgravity Sciences Glovebox
MSRF	Materials Science Research Facility
NASDA	Japanese Space Agency
SAGE	Stratospheric Aerosol and Gas Experiment
STBD S3/S4	Starboard Truss Segment S3/S4
USL	U.S. Lab
WORF	Window Observational Facility
XCF	X-ray Crystallography Diffraction System

Appendix D

Task Group and Consultant Biographies

TASK GROUP BIOGRAPHIES

James P. Bagian, *chair,* NAE**,** is the director of the Veterans Health Administration's National Center for Patient Safety (NCPS), which was established to develop and lead activities and programs concerned with improving patient safety. He is a diplomat of the American Board of Preventive Medicine with subspecialty certification in aerospace medicine and is a registered professional engineer. Dr. Bagian was a NASA astronaut for over 15 years, with extensive experience in aviation-related safety systems and human factors, and he served as one of the lead investigators of the Challenger Accident Investigation. Dr. Bagian chairs the VA Expert Advisory Panel on Patient Safety System Design. He is a faculty member of the Department of Preventive Medicine and Community Health at the University of Texas, a faculty member of the Department of Military and Emergency Medicine at the Uniformed Services University of the Health Sciences F. Edward Hebert School of Medicine, and a member of the board of directors of the Aerospace Human Factors Society. Dr. Bagian was a member of the NRC Steering Committee for the Workshop on Reducing Space Science Research Mission costs (1996-1997), a joint SSB and ASEB study; was a member of the SSB's Steering Group for a Workshop on Bionics for Space Exploration (1997-1998); and was chair of the Aeronautics and Space Engineering Board's Committee on Advanced Technology for Human Support in Space (1996-1997). Dr. Bagian previously served on the SSB from 1995 to 1997 and is currently a member of the SSB and chair of the Committee on Space Biology and Medicine.

Noel D. Jones, *vice chair,* is retired as research advisor (scientific director) and group leader of macromolecular struture research at Eli Lilly and Company, where he spent 27 years. Subsequently he was for 3 years vice president of drug design at Molecular Structure Corporation. He has extensive experience in macromolecular crystallography research, drug design, and research management. His special expertise is in the development of automated instrumentation for protein crystallization and in the development of synchrotron beam lines for diffraction studies. Dr. Jones has frequently served on NIH, NASA, and DOE review panels for evaluation of research programs. He served on the NRC Task Group for Evaluation of NASA's Biotechnology Facility for the International Space Station, 1999-2000.

Adele L. Boskey is director of research, Hospital for Special Surgery, and professor of biochemistry and cell and molecular biology at the Weill (Cornell University) Medical College. She also is an adjunct professor of bioengineering at the City College of New York. She investigates calcium phosphate crystal deposition within the extracellular matrices of bones, teeth, ligaments, and tendons in mammals using solution, cell culture, and in vivo models. Dr. Boskey had experiments fly on the space shuttle in 1994 and 1996 and has served on NIH-NASA advisory panels. She is a past president of the Orthopedic Research Society, and she served on the NRC Task Group for the Evaluation of NASA's Biotechnology Facility for the International Space Station, 1999-2000.

John F. Brady, NAE, is the Chevron Professor of Chemical Engineering at the California Institute of Technology. His awards and honors include the Joliot-Curie Professorship, Ecole Supérieure de Physique et de Chimie Industrielles, Paris, France (1988 and 1996); ASEE Curtis W. McGraw Research Award (1993); Corrsin Lecture in Fluid Mechanics, Johns Hopkins University (1995); J.M. Burgers Professor, Twente University, The Netherlands (1997); the G.K. Batchelor Lecture in Fluid Mechanics, DAMTP, University of Cambridge, England (1997); and the Professional Progress Award, AIChE (1988). Dr. Brady's research interests cover suspensions and colloids, applied mathematics and computational physics, fluid mechanics, and transport processes.

Jay C. Buckey, Jr., is a research associate professor of medicine at Dartmouth Medical School. He was coinvestigator on cardiovascular experiments on the SLS-1 space shuttle mission and was an alternate payload specialist for the SLS-2 space shuttle mission. In 1998 he flew as a payload specialist astronaut on the Neurolab space mission, STS-90, which focused on the effects of microgravity on the brain and nervous system. Dr. Buckey is immediate past president of the American Society of Gravitational and Space Biology and a member of the NRC Committee on Space Biology and Medicine.

Meredith B. Colket III is principal research scientist, AeroThermodynamics, United Technologies Research Center (UTRC). Dr. Colket has directed and/or participated in research in chemical kinetics, CVD processes, coal devolatilization, combustion of alternate fuels, measurement of nitric oxide, probe phenomena, fuels research, coking studies, soot formation (modeling and experiments), NO_x formation and control, catalytic combustion processes, and development of combustion models and pollutant submodels for CFD codes. Dr. Colket is serving or has served as program manager/principal investigator for several projects. His most recent projects include Mitigation of Particulate Formation in Engines via Fuel Additives, Fundamentals of Soot Formation in Gas Turbine Combustors, and Mechanisms Controlling Soot Formation in Diffusion Flames. He was the recipient of UTRC awards in several categories, including the 1989 Special Award for work on soot formation modeling, the 1990 Special Award for work on endothermic fuels, the 1992 UTRC Outstanding Achievement Award for work on a new catalytic combustion concept, and the 1997 Outstanding Achievement Award for contributing to development of a low NO_x combustor. Dr. Colket is a member of the American Chemical Society, the Combustion Institute, the American Association for the Advancement of Science, and the American Institute of Aeronautics and Astronautics. He has served as a member of the Discipline Working Group, Microgravity Combustion Science, since 1999 and as chair, Eastern States Section of the Combustion Institute, 1999-2001, and member, Advisory Committee 21st Symposium on Combustion, 1986.

Herman Z. Cummins, NAS, is Distinguished Professor of Physics at City College of the City University of New York. Dr. Cummins directs a program of laser light-scattering studies of liquids and solids. His major effort is in the study of phase transitions and critical phenomena, most recently involving the liquid-glass transition, using Raman and Brillouin scattering and photon correlation spectroscopy. He is noted as the coinventor of the laser Doppler velocimetry and pioneered light-scattering techniques to study the diffusion, size, and shape of particles in solution. His research has been concerned primarily with the application of light-scattering spectroscopy to a variety of problems in physics and materials science, primarily phase transitions and critical phenomena.

John H. Hopps, Jr., Northwestern University, is a former provost and senior vice president for academic affairs and professor of physics at Morehouse College. Prior to his position at Morehouse, he was director of the Division of Materials Research at the National Science Foundation. Dr. Hopps has served in numerous capacities at the Massachusetts Institute of Technology, in particular, at the Charles Stark Draper Laboratory, beginning as a research scientist in 1977 and later serving as manager of the Laser Research and Development Facility, chief of photonics, and principal member of the technical staff. He has a broad range of experience in the materials field and is known nationally for his speeches on the subject. Dr. Hopps is the author or coauthor of numerous articles and papers on materials science. He is a member of the American Institute of Aeronautics and Astronautics' Committee on Plasmadynamics and Lasers and the American Association for the Advancement of Science. Dr. Hopps is a former member of the NRC Committee on Materials Science Research for the International Space Station (April-November 1997) and the National Materials Advisory Board (1997-1999). He currently serves on the Space Studies Board.

Lynette Jones is a principal research scientist in the Department of Mechanical Engineering at the Massachusetts Institute of Technology. Her primary research is on the human proprioceptive system and the role of muscle and cutaneous mechanoreceptors in sensory processes. This research has led to studies of haptic interfaces that are used to interact with computer-generated virtual environments and teleoperated robots. She also does research on the development of wearable health monitoring devices and is involved in developing a portable system to evaluate the visual-vestibular system. Dr. Jones is a member of the Society for Neuroscience and the NRC Committee on Space Biology and Medicine.

Alan Lawley, NAE, is Grosvenor Professor of Metallurgy in the Department of Materials Science at Drexel University. Dr. Lawley's professional interests and activities involve teaching and research in the areas of physical and mechanical metallurgy, powder metallurgy, composite materials, materials engineering design, and engineering education. The overall mission of his research is to develop and exploit the science base of powder technology and to identify the complex relationships that exist between processing, microstructure, and properties, with a strong emphasis on particulate processing science. Current research focuses on the press and sinter processing of new ferrous alloys and on spray forming. Dr. Lawley is a fellow of APMI International and ASM International, is a former president of the Metallurgical Society (1982) and of AIME (1987), has consulted extensively for government and industry, and served as a member of the National Materials Advisory Board. He received the Distinguished Service to Powder Metallurgy Award of the Metal Powder Industries Federation (1991), the Jenkins Award of the Institute of Materials (1996), and the ASM Gold Medal (1996). He is editor in chief of the *International Journal of Powder Metallurgy*.

Robert A. Marcus is director of a program in clinical disorders of bone and mineral metabolism at Stanford University. His primary research interests are acquisition, maintenance, and regulation of bone mass in humans. His laboratory studies hormonal nutrition and physical activity determinants of bone mass. Dr. Marcus is a former member of the NRC Committee on Space Biology and Medicine.

Steven E. Pfeiffer is a professor of microbiology at the University of Connecticut Health Center. Dr. Pfeiffer has expertise in molecular cell biology and neurobiology. His research interests are in molecular, cell, and developmental biology of the nervous system and myelinogenesis. He is the recipient of the Javitz Neuroscience Investigator Award from the National Institutes of Health. Memberships include the American Association of Cell Biologists; American Society for Neurochemistry; International Society for Developmental Neuroscience, of which he is past president; and Society for Neuroscience. Dr. Pfeiffer is a member of the NRC Committee on Space Biology and Medicine.

CONSULTANT BIOGRAPHIES

David J. Pine, a retired senior executive with a 34-year career at the National Aeronautics and Space Administration (NASA), is a consultant to the National Academy of Public Administration, the joint participant in this study. At NASA, Mr. Pine's organizations in the Office of the Chief Financial Officer and later at the Langley Research Center were responsible for the conduct of major NASA program analysis and evaluation for the NASA Administrator and Deputy Administrator. All major programs, including the International Space Station, were reviewed annually by his organization. In addition, he led the agency's cost-estimating function. His organization provided NASA senior management with independent cost estimates and assessments of projects' cost postures to ensure cost realism in the development of agency budgets. From early 1988 through the end of 1990, Mr. Pine was the deputy program manager for the Hubble Space Telescope, specifically responsible for the telescope operations and science support aspects of the program.

Thomas E. Utsman, retired from the National Aeronautics and Space Administration (NASA), is a consultant to the National Academy of Public Administration. While at NASA, Mr. Utsman served as the space shuttle program director; deputy director of the Office of Space Flight; deputy director of the Kennedy Space Center (KSC); and the director of Space Shuttle Operations at KSC. During these assignments he developed a clear programmatic and operational understanding of human spaceflight.

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