SPACE STATION FREEDOM UTILIZATION CONFERENCE

VON BRAUN CIVIC CENTER
HUNTSVILLE, ALABAMA
AUGUST 3-6, 1992

Sponsored by:
Space Station Freedom Program
NASA Headquarters
Washington, D.C.
Dear Conference Participant:

I am pleased to present you with the proceedings of the first Space Station Freedom Utilization Conference held August 3-6, 1992. The conference is part of NASA's ongoing efforts to better inform current and prospective space researchers about the research potential of Space Station Freedom.

Freedom will be a world-class facility, an on-orbit laboratory which will support research and discovery in a variety of science and technology disciplines by those in academia, industry and government. We held the Utilization Conference to present Freedom's research capabilities, to describe current plans for research and to establish a forum for direct interaction between the Space Station Freedom Program and the research community.

We thank all participants for helping to make this a successful conference. It is clear that there is strong interest in the results of our nation's space research and in research opportunities aboard Freedom.

We take your comments to heart. Many of your suggestions for improving the program format and content are being used in our planning for the 1993 Utilization Conference. In particular, the next conference agenda will include more in-depth discussion of research results between the audience and "hands-on" space researchers. We will also present more detailed information about the many different experiment accommodations which will be available on Space Station Freedom. Please feel free to contact me at (202) 453-1180 if you have any further questions or comments.

Thank you again for contributing to the success of the 1992 Space Station Freedom Utilization Conference. We look forward to expanding our dialogue with the prospective Space Station Freedom research community and hope to see you at our next conference.

Sincerely,

John-David F. Bartoe
Director, User Integration Division
Spacelab/Space Station Utilization Program
Office of Space Flight
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"One of the challenges we face as a society...is to focus not on the present, but on the future."
-NASA Administrator Daniel Goldin

Introduction

From August 3-6, 1992, Space Station Freedom Program (SSFP) representatives and prospective Space Station Freedom researchers gathered at the Von Braun Civic Center in Huntsville, Alabama, for NASA's first annual Space Station Freedom (SSF) Utilization Conference.

Conference Chairman John-David Bartoe, Director of User Integration for the Spacelab/Space Station Utilization Program in NASA's Office of Space Flight, told attendees that the purpose of the conference was to bring together prospective space station researchers and the people in NASA and industry with whom they would be working to exchange information and discuss plans and opportunities for space station research.

The conference was the first annual meeting that NASA organized for space station researchers. Almost 700 people attended, including 500 who participated in the utilization conference and 200 who participated in a concurrent Space Station Freedom Payload Data Services Workshop. The attendees included approximately 100 researchers and 100 experiment hardware developers.

The conference featured more than three dozen exhibits sponsored by private companies, NASA offices, and foreign space agencies. The exhibits included mock-ups of hardware and potential experiments and provided information on equipment and services available to researchers on Space Station Freedom. (See List of Exhibitors, Appendix C.)

In a keynote address to participants, NASA Administrator Daniel Goldin said the conference was a needed and timely effort to spur the development of a space station research community. Freedom should be thought of as an international research center in space where researchers will be able to share facilities to do basic research in such disciplines as materials processing and biotechnology. Moreover, it will allow scientists to perform life sciences research necessary for...
missions to the Moon and Mars. He urged those in attendance to spread the word about research opportunities on Freedom, with the aim of doubling or tripling the number of researchers at next year's utilization conference.

In plenary and splinter sessions, speakers described space station capabilities, plans and opportunities for research. Freedom will accommodate experiments in its laboratory modules and observational payloads mounted external to the modules. It will provide researchers access to the microgravity environment of space, with resources such as power, communications and crew time to perform experiments. In addition, laboratory support equipment such as refrigerators and gloveboxes will be available to support experiments. NASA research organizations also will be developing facilities that will support a broad range of research. Such facilities include the Fluid Physics Dynamics Facility, Advanced Protein Crystal Growth Facility and a 2.5 meter Life Sciences Centrifuge.

Opportunities for flying space station precursor experiments were also detailed — for instance, Get Away Special payloads, the Office of Commercial Programs' Wakeshield Facility for high-vacuum research, Spacelab missions, and the Office of Aeronautics and Space Technology's In-Space Technology Experiment Program (IN-STEP). Researchers with space flight experience described what it is like to work in space and what kinds of services crew members can offer to investigators.

NASA officials told attendees that the first research initiatives on Space Station Freedom may be flying just five years from now. Investigators associated with the Spacelab Life Sciences 1 (SLS-1) mission launched on the Space Shuttle in June 1991 and the U.S. Microgravity Laboratory 1 (USML-1) mission launched in June 1992 spoke at the conference. They reported on the results of space station precursor experiments in life sciences and materials processing that were conducted on these flights. Crew members of other Space Shuttle missions dedicated to science told researchers how to make the most of human presence in orbit.

NASA officials explained the kinds of research that the agency's various "user" organizations support, so that prospective space station researchers could determine where to seek sponsorship. These organizations — the NASA program offices that sponsor space-based research — are the Office of Aeronautics and Space Technology, Office of Commercial Programs, Office of Space Flight, and Office of Space Science and Applications. Representatives of these organizations explained how NASA announces research opportunities and how researchers obtain sponsorship.

Representatives of the international partners in Space Station Freedom — the Canadian Space Agency, European Space Agency, and National Space Development Agency of Japan — told conference attendees about their plans for research on Freedom. These presentations made it clear that international cooperation in space research is not an option; it is a given.

**Welcome Lunch**

"We're building the space station for you."

This conference theme was articulated by Spacelab/Space Station Utilization Division Director Robert Parker of NASA's Office of Space Flight.

Now is the right time for members of the research community to gather together and discuss what they want to do and how they want to do it, NASA Associate Administrator for Space Systems Development Arnold Aldrich told attendees. Aldrich discussed NASA's plans for extended-duration (up to 14 days) and
long-duration (14-28 days) Space Shuttle missions that will serve as space station precursor missions.

Plans are now in the works for joint U.S.-Russian missions in space, including the flight of a U.S. astronaut on a long-duration mission to the Russian space station Mir. He also reported that NASA is considering the purchase of Russian Soyuz spacecraft used to transport crews to and from the Mir space station. These spacecraft could serve as Assured Crew Return Vehicles (ACRVs), or “lifeboats,” for Space Station Freedom crews.

Session 1: Overview and Research Capabilities

Space Station Freedom Director Richard Kohrs, Office of Space Systems Development, NASA Headquarters:

NASA field centers and contractors are organized to develop “work packages” for Space Station Freedom. Marshall Space Flight Center and Boeing are building the U.S. laboratory and habitation modules, nodes, and environmental control and life support system; Johnson Space Center and McDonnell Douglas are responsible for truss structure, data management, propulsion systems, thermal control, and communications and guidance; Lewis Research Center and Rocketdyne are developing the power system.

The Canadian Space Agency (CSA) is contributing a Mobile Servicing Center, Special Dextrous Manipulator, and Mobile Servicing Center Maintenance Depot. The National Space Development Agency of Japan (NASDA) is contributing a Japanese Experiment Module (JEM), which includes a pressurized module, logistics module, and exposed experiment facility. And the European Space Agency (ESA) is contributing the Columbus laboratory module.

NASA ground facilities that are now in various stages of development to support Space Station Freedom include: Marshall Space Flight Center’s Payload Operations Integration Center and Payload Training Complex (Alabama), Johnson Space Center’s Space Station Control Center and Space Station Training Facility (Texas), Lewis Research Center’s Power System Facility (Ohio), and Kennedy Space Center’s Space Station Processing Facility (Florida).

In Fiscal Year 1988, Congress appropriated only half of the funds that NASA requested for the space station program ($393 million vs. $767 million). In FY 89, NASA sought $967 million for the program, and Congress appropriated $900 million. NASA's FY 90 request was $2.05 billion compared to an appropriation of $1.75 billion; the FY 91 request was $2.45 billion, and the appropriation was $1.9 billion.

After NASA restructured the Space Station Freedom program in response to directions from Congress, the agency’s full budget request of $2.029 billion for Space Station Freedom in FY 92 was appropriated. For FY 93, NASA is seeking $2.25 billion for the program; the planned budget for FY 94 is $2.5 billion. Further alterations to the hardware configuration for Freedom would be a serious setback; NASA intends “to stick with the current baseline” and continue planning for utilization.

Space Station Freedom Program and Operations Deputy Director Robert Moorehead, Office of Space Systems Development, NASA Headquarters:

NASA’s plan for building up space-based research capabilities begins with extended-duration Space Shuttle missions that will
double the research capability currently provided by Spacelab and culminate in Space Station Freedom. The 14-day USML 1 mission flown on the Space Shuttle in June 1992 was a space station precursor mission, dedicated to microgravity and life science research.

Freedom will be a permanent space-based research facility, providing a working environment nearly free of buoyancy-driven convection, sedimentation, and hydrostatic pressure and featuring access to the ultra-high vacuum of space (for external payloads). In its crew-tended phase, Space Station Freedom will provide 40 times Spacelab’s capability, and in its permanently occupied phase, Freedom will provide 110 times Spacelab’s capability. (The Russian space station, Mir, offers 26 times Spacelab’s capabilities.)

According to NASA’s current schedule, the first launch of a space station element will take place in November 1995, with permanently occupied capability planned for September 1999. This year, NASA will conduct space station critical design reviews (CDRs). Work package design reviews will take place from February to April 1993, followed by a systems CDR.

**Space Station Freedom Program Chief Scientist, Robert Phillips, Office of Space Systems Development, NASA Headquarters:** NASA has allocated research accommodations on Freedom (equipment, utilities, etc.) to the program offices that sponsor space-based research and development as follows: Space Science and Applications (OSSA) — 52 percent, Commercial Programs (OCP) — 28 percent, Aeronautics and Space Technology (OAST) — 12 percent, and Space Flight (OSF) — 8 percent.

Most of OSSA’s allocation will be used for microgravity and life science experiments, although OSSA’s space physics, astrophysics, earth science and applications, and solar system exploration divisions also will use some of this allocation.

Other Federal agencies have expressed interest in using Space Station Freedom. They
Include the National Institutes of Health (NIH), U.S. Geological Survey, National Science Foundation, National Oceanic and Atmospheric Administration, and U.S. Departments of Agriculture and Energy. NIH and NASA have already signed a memorandum of understanding regarding joint space research.

Payload interfaces with space station lab support equipment must be simple, and experiment packages must be highly contained. Freedom’s research facilities will feature International Standard Payload Racks (ISPRs), experiment racks that are about twice the size of a Spacelab rack. ESA’s Columbus lab will feature 20 racks, the U.S. lab will have 12 racks, and the Japanese lab will have 10. Thus Freedom will have a total of 42 racks versus 8 for Spacelab.

NASA is considering outfitting some rack space to accommodate small, self-contained payloads similar to the Get-Away-Special canisters and middeck-locker experiment packages flown on Space Shuttle missions. Because of the large number of planned experiments, crew time allotted to experiments on Freedom at permanently occupied capability will average 25 minutes per rack per day, compared to six hours per rack per day on Spacelab missions. Hence, telescience — the remote operation of space-based experiments by researchers on the ground — will play a very important role in space station research.

Plans for supporting life sciences research on Freedom focus on the two basic goals of NASA’s space life sciences program: to ensure the health, safety, and productivity of humans in space and to acquire fundamental knowledge of biological processes. Today, “there are no known factors” that will limit long-duration human stays in space.

Space-based research has already shown that people and plants respond the same way to the microgravity environment: they lose structure. However, the mechanisms by which they respond are different, and researchers do not yet know much about these mechanisms. Life science research accommodations on Freedom will include facilities for experiments designed to address this and other questions, in fields such as gravitational biology, space physiology, and biomedical monitoring and countermeasures research.

**User Integration Division Director John-David Bartoe, Spacelab/Space Station Utilization Program, Office of Space Flight, NASA Headquarters:**
Researchers who want to use NASA facilities must find a NASA sponsor. The agency’s program offices periodically issue announcements of opportunity (AOS) for research proposals involving major hardware procurements and NASA research announcements (NRAs) for proposals involving existing hardware or minor hardware procurements.

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<th>MICROGRAVITY RESEARCH</th>
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<tr>
<td>- Electronic and photonic materials</td>
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<td>- Metals, alloys and composites</td>
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<td>- Glasses and ceramics</td>
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<tr>
<td>• Fundamental sciences</td>
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<td>- Fluid dynamics and transport phenomena</td>
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<td>- Combustion science</td>
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<td>- Gravitational physics</td>
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<td>• Biotechnology Experiments</td>
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<td>- Macromolecular crystal growth</td>
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<th>LIFE SCIENCES RESEARCH</th>
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<tr>
<td>• Crew health, safety and productivity</td>
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<td>- Monitor crew health</td>
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<tr>
<td>- Develop countermeasures to adverse effects of prolonged exposure to low gravity</td>
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<tr>
<td>• Basic and applied research</td>
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<tr>
<td>- Study effects of gravity on living systems</td>
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<td>- Cell and tissue growth</td>
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<td>- Biologically based support systems</td>
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<th>TECHNOLOGY RESEARCH</th>
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<td>• Structural dynamics and control</td>
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<td>• Space materials and environmental effects</td>
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<td>• Space power systems</td>
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<td>• Thermal management</td>
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<td>• Fluid management</td>
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<td>• Propulsion</td>
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<td>• Automation and robotics</td>
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<td>• Sensors</td>
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<td>• Information systems</td>
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Long-Term Research Objectives.
OSSA’s Microgravity Science and Applications Division is in the process of releasing a series of discipline-oriented NRAs for fundamental physics and chemistry, materials science, and biotechnology investigations to fly on Freedom. OSSA’s Life Sciences Division plans to release its first NRA for space station investigations in about two years.

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<td>• 1 Habitation Module</td>
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<tr>
<td>• 2.5 m (8.2 ft) Centrifuge Facility</td>
</tr>
<tr>
<td>• Pressurized working environment</td>
</tr>
<tr>
<td>• 42 International Standard Payload Racks</td>
</tr>
<tr>
<td>For Payloads:</td>
</tr>
<tr>
<td>• Power - 30 kW</td>
</tr>
<tr>
<td>• Thermal Control - 30 kW</td>
</tr>
<tr>
<td>• Data Transmission Rate - 50 Mbps</td>
</tr>
<tr>
<td>• A permanent crew of 4 with 2 dedicated to research</td>
</tr>
<tr>
<td>• 4 attachment points to truss for external payloads</td>
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<tr>
<td>• 10 locations for external payloads on JEM Exposed Facility (zenith, nadir, wake viewing)</td>
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NASA’s Office of Aeronautics and Space Technology plans to release an NRA shortly for robotics, life support, thermal management, and other technology development and validation experiments that require some sort of flight testing. The Office of Commercial Programs seeks cooperative research proposals in which NASA provides space flights in return for access to experimental data. A national network of 17 Centers for the Commercial Development of Space, cosponsored by NASA and private-sector partners, provides a way for prospective commercial users of space to work with the agency.

NASA is developing a policy that will establish the price commercial reimbursable researchers will pay for access to Freedom’s accommodations, resources, and standard services. Space requirements, energy consumption, crew time needs, and length of stay in space will be considered in establishing the prices. The space station pricing policy will be based on the agency’s existing Space Shuttle and Spacelab pricing policy.

NASA is planning Space Station Freedom flights using a five-year planning horizon, but researchers will not get involved in the flight planning process this far in advance unless their payloads are very complex.

All space station researchers will be assigned payload accommodations managers to work with them throughout the payload integration process. This process encompasses analytical integration — “a paper process” addressing detailed payload requirements, physical integration (including optional functional testing), and operations integration (compatibility, interface with crew, uplink commands).

Because 60 percent of payloads proposed for Space Station Freedom thus far require less than one rack of space, NASA wants to be able to handle small payloads in a fast, simple fashion. “The payload integration process is being streamlined to better accommodate researchers”, NASA’s goal is to complete space station payload integration in less than a year.

Session 2: Research Plans and Opportunities

Deputy Assistant Administrator Ray Arnold, Office of Commercial Programs, NASA Headquarters:

Between now and the time that Space Station Freedom is available, NASA’s Office of Commercial Programs (OCP) can arrange for the launching of commercial experiments on facilities ranging from sounding rockets to expendable launch vehicles to Spacelab and Spacehab (a commercial pressurized lab module designed to fly in the Space Shuttle cargo bay) and a Wakeshield Facility being developed to accommodate high-vacuum research. Toward creating an industry-driven research environment in space, OCP is focusing its resources on NASA’s national network of Centers for the Commercial Development of Space (CCDS).

Joint endeavor agreements (JEAs) are among the means by which OCP currently arranges to fly commercial experiments on NASA missions; OCP is working on new legal instruments that will further ease commercial access to space. OCP’s Space Station Freedom utilization flight plan shows seven racks in use for commercial research by 1997. OCP has a
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commercial Space Station Freedom planning team in place, including CCDS representatives and JEA partners.

Director for Space W. Ray Hook, NASA Langley Research Center:
Over the last 25 years, NASA’s Office of Aeronautics and Space Technology has logged quite a bit of space flight experience that will aid in planning space station research: 26 experiments on Skylab missions, 8 on expendable launch vehicles (ELVs), and 12 on the Space Shuttle. OAST technology initiatives begin with basic research and proceed to proof of feasibility, technology development, subsystem and system development, and system testing, launch, and operations.

OAST’s current activities include a research and technology (R&T) program, the Civil Space Technology Initiative, and the In-Space Technology Experiments Program (IN-STEP). IN-STEP sponsors the design, development, and flight of technology experiments for private-sector, academic, and NASA researchers on ELV, Space Shuttle, and Space Station Freedom missions.

Some of OAST’s most recent technology investigations include a tank-pressure-control experiment flown as a Get Away Special payload on the Space Shuttle in August 1991, a middeck zero-gravity experiment flown in September 1991 to measure truss-structure and fluid-slosh dynamics, and an orbital acceleration research experiment flown in June 1992.

This summer, OAST plans to release a new AO that will solicit proposals for space technology experiments to fly on Space Station Freedom beginning in 1997. OAST will select 50 proposals for concept development in the areas of space materials and coatings, cryogenic fluid handling, human support, space power, vibration isolation, space communication, in-space construction and repair, and sensors.

Space Station Utilization Branch Chief Philip Cressy, Flight Systems Division, Office of Space Science and Applications, NASA Headquarters:
NASA’s Office of Space Science and Applications (OSSA) will use Space Station Freedom to further its goal of studying physical, chemical, and biological processes in the space environment. OSSA’s goals are to advance knowledge of the Earth, the solar system, and the universe; use the unique qualities of the space environment to advance research; and expand human presence into the solar system.

OSSA’s strategic plan includes a Space Shuttle-to-Space Station Freedom transition plan, focused on the use of Freedom to support preparations for long-duration human missions in space. OSSA’s strategy for using Freedom calls for ensuring a range of utilization options, from small self-contained or rapid-response payloads to attached payloads and facility-class payloads.

For facility-class payloads, OSSA will solicit research proposals three years before flight and assemble science teams for investigations two years before flight. OSSA’s Life Sciences Division has developed a strategy for using Freedom as follows: Phase 1, Biomedical Monitoring and Countermeasures (BMAC) Program; Phase 2, building of a national/international life science research capability; and Phase 3, establishment of an international life science facility for in-depth studies of medical issues related to long-duration human missions in space.

The Microgravity Science and Applications Division has outlined its utilization strategy as follows: Phase 1, provision of transitional

Inside the U.S. Laboratory Module.

Monitor

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hardware for use during crew-tended stage; Phase 2, provision of facility-class hardware during crew-tended stage; and Phase 3, onboard research during permanently occupied capability and evolution to crew-tended free flyers.

Prospective researchers asked whether crew movements on Space Station Freedom would disturb experiments requiring a carefully controlled microgravity environment. NASA officials reported that the effects of crew movements are being monitored on Space Shuttle missions, but thus far it has been difficult to separate the effects of crew movements from other factors in play. Researchers have nothing conclusive to report on how crew movements might affect the microgravity environment.

**U.S. Microgravity Laboratory 1 Payload Specialist Larry DeLucas (associate director for protein crystal growth, Center for Macromolecular Crystallography, University of Alabama in Birmingham):**

Protein crystallography — a research tool used to study the structure of the complex building blocks of living systems — has a lot to gain from space-based research. In order to know how a protein works in the human body, researchers must understand its molecular structure. Researchers have identified 150,000 different proteins in the body, but they know the structure of fewer than a third of them.

The only viable technique for analyzing the structure of these proteins is x-ray diffraction of the proteins in their crystal form. The better the quality of a protein crystal, the more useful it is to researchers who are trying to delineate its structure. The microgravity environment of space allows protein crystals to grow nearly undisturbed by convection and other gravity-driven forces that cause flaws to form in them on the ground. In space, lack of convection enables protein crystals to grow more slowly than they do on Earth, and the slower a protein crystal grows, the fewer flaws it will have.

Protein crystal growth experiments have already flown on 14 Space Shuttle missions. This year's USML-1 Spacelab mission included protein crystal growth experiments conducted for commercial researchers.

DeLucas, the first payload specialist with expertise in protein crystal growth research, performed protein crystal experiments on USML-1. The results of protein crystal experiments flown thus far have been larger crystals with more uniform morphologies.

The Center for Macromolecular Crystallography (a NASA-cosponsored CCDS) currently builds flight hardware to meet researchers' needs and handles sample loading and retrieval for flight experiments. "The sample approval process is rapid"; NASA will approve a change in sample material in a matter of days. The results of commercial experiments are not made public.

Protein crystallography enables "rational drug design": the development of drugs that bind only with the target protein and, hence, do not cause side effects. For example, pharmaceutical companies presently are interested in developing drugs that can inhibit purine nucleoside phosphorylase (PNP), a protein that plays a role in auto-immune diseases. To continue these kinds of investigations, researchers need a constant supply of protein crystals that are as free of flaws as possible.

Space Station Freedom will provide the kind of research environment that will enable the production of such supplies. In addition, Freedom will provide the kind of long-duration facility required by protein crystal researchers: 40 percent of proteins require more than two weeks to crystallize. And
finally, “to try to automate this process would be fruitless”: a permanently occupied facility is required for the conduct of this kind of research.

The Center for Macromolecular Crystallography is now working on a thermal enclosure system for crystal growth investigations in the Space Shuttle middeck and on Space Station Freedom; this system will have a 50-pound payload capacity and feature a hermetically sealed, controlled temperature environment. Ultimately, installing an x-ray generator on Freedom would enable scientists to analyze the results of crystal growth experiments in orbit, reducing the loss of samples due to deterioration or the stresses of reentry.

**Keynote Address: NASA Administrator Daniel Goldin**

(In an address to conference attendees, NASA Administrator Goldin urged prospective space station researchers to recruit their colleagues for next year’s utilization conference: “the more you learn about possibilities on Space Station Freedom, the more you get excited.” Citing Freedom as an example of “how nations can work together on projects of peace instead of weapons of war,” he urged the research community to think of Freedom as NASA’s newest field center and “the first international research center in orbit.” The text of Goldin’s speech follows):

One of the challenges we face as a society — certainly in this period of slow economic growth — is to focus not on the present, but on the future. I believe one of the reasons we’re having problems with our economy is that we’re not investing in our future to the degree we should.

When I was born in 1940, there were about two billion people on Earth. Today, that’s more than doubled to 5.5 billion. And when I’m 100 years old, there’ll be almost 10 billion. The people alive during my life have consumed more of the world’s resources than all those living in prior generations of human history. We’ve already used more than we deserve, and now we’re stealing from the future to buy the creature comforts of today.

We see it in government, where we have big deficits year after year. We see it in the corporate world, where the focus is on short-term profits, not long-term investment. Last year, the aerospace companies that invested the least in research and development saw their stock prices go up the most. While the rest of the world gears up for the economic competition of the post-Cold War era, America is chowing down on its seed corn to feed its belly today.

NASA scientist Rick Chappell, who works at Marshall, recently had an experience that illustrates this quite clearly. As he jogged through the wildlife refuge that surrounds the launch pads at Cape Canaveral, he noticed an armadillo by the trail. Later, he looked up and saw an eagle.

He wrote later on, “I was struck by the contrast of their different approaches to life. Where the armadillo never looks up — concentrating only on its next meal, and oblivious to the world around it — the eagle soars quietly and majestically. It is not rooting around the ground, but is striving for the high ground — seeking a vantage point from which to see the horizon and beyond.”

America’s first spacecraft that landed on the Moon wasn’t called the armadillo; it was the Eagle — the symbol of America. This nation didn’t become the greatest in the world by keeping its eyes on the ground. We are about broad visions, about looking over the horizon
to see the future, and then blazing the trail for others to follow.

Technology is the fuel in our economic furnace. Technology creates growth. It creates whole new industries and new jobs — high paying, high quality jobs that add value to our economy.

NASA's research and development of advanced technology reaches out into the future to bring back opportunities to the world of today. Between 1979 and 1986, the new products generated from NASA science and engineering created over 350,000 new jobs. And believe me, this is a very conservative estimate, because once NASA invents something and makes it available to industry, we lose track of the many by-products that build on our pioneering work.

NASA has been driving technology forward ever since it was created. Apollo brought us untold bounty — especially in medical technology. Pacemakers, CAT scans, magnetic resonance imaging, intensive care monitoring equipment — all got their start because of research NASA needed to go into space. Mission Control's computer networks and software are the great grandfathers of what runs America's telephone system, banking and credit card networks, and airline computer networks.

But we can't keep living off Apollo's bounty. Currently, the hair of a scientist can turn gray waiting to get his or her first experiment on the shuttle, let alone the necessary follow-up research. A researcher can't make much progress doing one experiment every few years or so. We can't keep attracting good people to do space science if the research they need for their Ph.D.s takes decades to complete.

The House of Representatives took a giant leap in the right direction last week when they voted to continue building Space Station Freedom. As I listened to the debate in the House Chamber and watched the vote tally grow, I was proud that in these difficult economic times, Congress saw the wisdom in investing in our future. It was not just a victory for NASA, but a victory for America and its international partners, who desperately need the research and technology that will come from a permanent facility in space.

Space Station Freedom will revolutionize our way of life in the 21st century the same way the Apollo program did in the 20th century.

A permanent space station will be the place where we become a true space-faring nation — the place where we learn how to live and work in space. And it will be an example of how nations can unite and work together on projects of peace. All of our plans to build an outpost on the Moon and explore Mars depend on using Space Station Freedom to conduct the necessary life science research to protect astronauts' health from the effects of long-duration space travel.

While these studies are going on, the space station will have dual use lab equipment where scientists can systematically study how living organisms and other materials behave without gravity. Essentially, the space station should be thought of as an international research center in orbit. Researchers from universities and the private sector, such as pharmaceutical companies, and our international partners will be able to share facilities on Freedom to facilitate basic research in materials processing, biotechnology, and life sciences.

Biotechnology, for instance, is expected to be the big business of the 90s, going from $4 billion a year currently to $50 billion by the
end of the decade — revolutionizing everything from agriculture to pollution control to health care. The commercial possibilities of biotechnology research in microgravity are mind-boggling. Product improvements developed from this research can fuel the furnace of our economy, creating new jobs and saving lives with new drugs and medical knowledge.

The stunning success of the U.S. Microgravity Lab on the last shuttle flight showed the vast potential of Space Station Freedom. On that flight was Astronaut Larry DeLucas of the University of Alabama at Birmingham, who's an expert in growing protein crystals, which are key to developing new drugs. The protein crystals grown on that flight were some of the largest and best-formed ever. Drug companies and other researchers had attempted to grow some of them on Earth to no avail. One drug company said they accomplished in two weeks an experiment that would have taken two years on the ground.

Yet despite this successful shuttle mission, DeLucas reached two conclusions: 1) that even a 14-day shuttle flight was not enough time for some of the experiments, and 2) a lab is needed in which scientists can interact and manipulate the experiments on a day-to-day basis.

That's why we need Space Station Freedom. The tidal wave of research that's waiting to be flown in space is what can let us live longer lives, in a cleaner environment, with a higher standard of living.

Clearly investing in the future is worth it, but at what cost? Many people don’t realize that NASA receives only 1 percent of the federal budget. Space Station Freedom's yearly cost is about one-seventh of that — literally two cents a day for every American citizen. When you consider the enormous return on investment a space station will yield, Americans will get far more than their two cents' worth. For that small amount, the dividends we pay are enormous.

Life on Earth is better because of the lives we’ve sent into space. Thank goodness we have a president that understands how important space is to the strength, and competitiveness, and future economic growth of America. George Bush and Dan Quayle support a robust civil space program because they’ve seen how science and technology drives this nation forward. Our international partners know this as well, which is exactly why they’ve joined us.

Every time we have gone to the frontier, we’ve brought back more than we could ever imagine. Space is no longer just an experiment or a symbol. It’s no longer a “luxury,” the way automobiles and air travel were once viewed. Space is an essential part of our future in medicine, science, and technology.

We have to get bold again. We have to take risks and make investments so our children will have a better future. By reaching for the stars, we bring inspiration, hope, and opportunity back to Earth.

The “armadillos” of the world cannot defeat those of us who choose to be eagles. By flying higher, and seeing farther, we will use our vision to lead the way for the benefit of all humanity.

Let me leave you with a vision of what the space station could mean. It’s early in the next century, and a woman in Montgomery, Alabama goes to her doctor to receive a hormone shot to prevent osteoporosis. That night, she sees on TV that a young astronaut at Kennedy Space Center just received the same shot to prevent bone loss before blasting off on the long journey to Mars.

That young astronaut grew up in Huntsville, where decades before, her father was a builder of Space Station Freedom, on which the life science research for long-term space flight uncovered the hormone that prevents osteoporosis. Her father’s work on Space Station Freedom had inspired her to study organic chemistry so that when the time came, she’d be qualified to go search for signs of ancient life on Mars.

Space Station Freedom isn’t just a job, or a chance to make money. It’s a mission to move the human species into breaking the chains of gravity and becoming a multi-planetary society. Pursuing a mission of this monumental importance will lift civilization on Earth to new heights of health, wealth, and knowledge.
The exploration of space is the most inspirational adventure of all time. Our work offers hope that our children's world will be a better place than our own. Join me as we make this vision a reality.

Session 2: Research Plans and Opportunities (continued)

Space Station Program Deputy Director Tosshio Mizuno, National Space Development Agency of Japan (NASDA):
The National Space Development Agency's contribution to the Space Station Freedom Program is the Japanese Experiment Module (JEM). The agency's JEM utilization policy calls for a national research program to promote utilization, the development of multipurpose facilities, space station precursor missions, and the release of announcements of opportunity to solicit experiment proposals.

Japan is in the process of implementing a joint research plan under which core research institutes such as the Institute for Space and Astronautical Science (ISAS) will manage space-based investigations, with NASDA providing flight hardware and flight opportunities.

As part of its effort to develop generic JEM experiment support technology, NASDA is conducting microgravity investigations using drop tubes (one operational since 1991, another to become operational in 1993), parabolic aircraft flights (since 1990), and suborbital rockets (five materials processing and fluid physics experiments per flight, one flight per year from 1991 to 1993).

In addition, NASDA has flown two experiments on the International Microgravity Laboratory (IML-1) mission of January 1992 and has booked 12 more experiments on IML-2, to be launched in July 1994. A dedicated Spacelab Japan (SL-J) mission to be launched on the Space Shuttle in September 1992 will carry 34 experiments developed by Japan.

A Japanese space experiment data base has been in operation since January 1992; it will be translated into English by mid-1993. NASA has installed a telescience test bed at its Space Experiment Laboratory, which became operational at the Tskuba Space Center in June 1992; a JEM telescience demonstration is scheduled there for November 1992.

A wet-environment training facility for JEM crew candidates is under construction. A JEM
mission specialist candidate was selected in April 1992, and a JEM system review is scheduled for October 1992. Eight multi-user facilities for JEM are now in the design study phase. JEM technology development will continue until early 1993.

Manager of Space Station Operations and Utilization James Faulkner, Canadian Space Agency:
The Canadian Space Agency (CSA) plans to use its three percent allocation of space station resources for materials science and life science investigations. Research plans encompass exploratory, fundamental, and applied science.

CSA’s first solicitation of interest in space station research drew more than 130 responses, including 52 percent for materials science investigations and 17 percent for biology and life science experiments. In evaluating these proposals, discipline review panels will consider factors such as commercial potential, cost, and national and scientific value. A Canadian Space Station Program Allocation Board will select experiments for flight.

Investigators will cover some payload development costs, and CSA will cover payload integration, launch, and recovery. CSA currently supports four test facilities for space station researchers: a laser test system, large motion isolation mount, float zone furnace, and protein crystallization apparatus.

CSA’s space station user support program ultimately will include technical support centers, a payload integration center, and payload operations and payload support centers. The latter two facilities will be part of a new space center at St.-Hubert, Quebec, scheduled for completion in November 1993.

Head of Microgravity and Columbus Utilization Jean-Jacques Dordain, European Space Agency:
The European Space Agency (ESA) plans to use any and all facilities available for space-based research — Spacelab, Spacehab, and the Russian space station, Mir, as well as ESA’s Columbus laboratory module for Space Station Freedom. The Columbus module will feature 20 racks; half will be for ESA researchers. Six racks will be integrated with the International Standard Payload Rack.

Columbus module before it is launched to Space Station Freedom so that research can begin immediately.

ESA is considering the addition of an external viewing platform to Columbus for attached payloads: the structure will be based on that of ESA’s Eureca free-flying platform. As part of its plans for developing space-based investigations so that they will not burden crew members with routine tasks, ESA already is operating telescience and robotics test beds in the Netherlands; these facilities are available free to any researchers interested in using them.

Spacelab Life Sciences 2 Payload Specialist Candidate Laurence Young:
Long-duration investigations and experiments using multiple generations of plants and animals are necessary to address key questions in the space life sciences. Space Station Freedom will enable researchers to fly a
sufficient number of experimental subjects to produce statistically significant results.

The fact that Freedom will be permanently occupied means that crew members can redesign experiments on the spot, an option especially important to the life sciences. Life science requirements for Space Station Freedom include two-way communication links, sample return, onboard analysis, bioisolation, and normal atmospheric conditions.

Equipment planned to support life science research on Freedom includes a glovebox to protect crew and samples, animal and plant holding facilities, a 2.5-meter-diameter centrifuge, and a health maintenance facility. The centrifuge is especially important because it will provide a one-g control environment as well as a range of microgravity environments for investigations.

Space physiology investigations thus far have shown that fast-twitch muscle fibers gradually replace slow-twitch fibers in the absence of gravity, bones lose calcium and overall mass, blood cell count and plasma volume decreases, the immune system changes, and the neurovestibular system adapts to the microgravity environment. The mechanisms by which all of these changes take place are not understood. More frequent and longer-duration flight opportunities are needed to pursue this line of research.

Director Liya Regel, International Center for Gravity Materials Science and Applications, Clarkson University (former head, material science department, Institute for Space Research, Soviet Union):

Materials science experiments flown on the Soviet Salyut space stations and Russia’s present-day Mir have yielded interesting results. Crystal growth experiments on the Salyuts and Mir have yielded zeolite crystals several times larger than the largest produced on Earth and the first crystals produced by rapid mixing of two solutions.

The latter result has helped to optimize terrestrial crystal growth. During the first year of operations on Mir’s Kristall materials processing laboratory module, researchers produced 100 kilograms of high-quality semiconductor material. Materials processing hardware currently installed on the Kristall module includes the Gallar and Crater tube furnaces, the Splav gradient furnace, and the Optizone mirror furnace for float-zone melting of silicon.

However, problems such as insufficient power, mass restrictions, inadequate operating time, and limited space-to-ground communications have affected materials science investigations on Soviet/Russian space station facilities, because engineers have designed experiments without input from the research community.

Other problems affecting Russian microgravity research include a lack of accelerometer data, lengthy delays in sample and data returns, excessive paperwork, unknown experiment selection criteria, and insufficient preflight training of cosmonauts with experiment hardware.

Replication of experiments is rarely possible in the Russian space program, and researchers do not receive support for thorough analyses of flight test results. Mir hardware is already old, and its solar power system is inadequate: for instance, the conduct of a materials processing experiment may require the diversion of power for hot water and cooking.
In addition, foreign investigators can get experiments on the Mir faster than Russian investigators can. And finally, Russian investigators cannot accompany their experiments to the launch site but must deliver them to NPO Energia in Moscow for delivery by Energia officials.

**Session 3: Life Sciences Research**

*Session Chairman Larry Chambers (Space Station Life Sciences Program Manager, Life Sciences Division, NASA Headquarters):* NASA’s Life Sciences Division sponsors investigations that fulfill the goals and objectives of ensuring the health, safety, and productivity of humans in space; acquiring fundamental scientific knowledge in the space biological sciences; expanding our understanding of life in the universe; and better understanding the role of gravity in living systems. NASA has identified life sciences research priorities for Space Station Freedom in consultation with a number of expert advisory groups such as the Committee on the Future of the U.S. Space Program and the NASA Advisory Council.

Spacelab-class life sciences investigations will be conducted during the crew-tended phase of Space Station Freedom. Once Freedom is permanently occupied (ca. 2000), NASA’s Life Sciences program will provide a suite of five discipline-focused “common-core” life sciences research facilities for investigations of up to six months: the Biomedical Monitoring and Countermeasures Facility (four racks, 1997 launch); Gravitational Biology Facility (two racks, 1998 launch); Centrifuge Facility (2.5-meter centrifuge plus habitat racks, late 1999 launch); Gas Grain Simulation Facility (one rack, 1998 launch); and Controlled Ecological Life Support System (CELSS) Test Facility (two racks, 1999 launch). All dates are for planning purposes.

NASA’s Office of Space Science and Applications and Office of Space Flight will provide lab support equipment for life sciences and other investigations. European, Japanese, and Canadian facilities on Freedom will be available to support life sciences investigations as well. In addition, the Italian Space Agency is negotiating with NASA to build a mini-life science laboratory module to be installed at a space station node.

*Space Station Life Sciences Program Scientist Richard Keefe, Life Sciences Division, NASA Headquarters:* NASA’s Life Sciences Division has consulted with the NASA Advisory Council’s Aerospace Medicine Advisory Committee and a network of 13 Discipline Working Groups (DWGs) to identify space life science initiatives that should be pursued and plan solicitations of space station life science investigations. The DWGs, comprising mostly non-NASA researchers, have developed implementation plans prioritizing scientific questions to be addressed in the various life science disciplines (e.g., neuroscience, radiation health, plant biology).

The Life Sciences Division’s strategy for using Space Station Freedom is to establish and maintain an international research laboratory there, provide routine access to this facility by regularly issuing discipline-focused NRAs and AOs (approximately every two years), and create an international life sciences archive and data base to facilitate research.

NRAs are used to solicit proposals for ground-based research and flight projects using existing hardware; AOs are used to solicit proposals for flight projects requiring major hardware development. The Life Sciences Division also accepts unsolicited proposals for experiments that would use existing hardware.
All proposals are subject to peer review. Evaluation criteria include scientific merit, relevance to NASA's mission, technical requirements, hardware availability, and cost. NASA's life sciences research budget is $55 million for the current fiscal year; about half of those funds are granted to non-NASA researchers. The average grant or contract for a space life science experiment will be $60,000-$100,000 per year.

On Space Station Freedom, life science flight opportunities will include nominal use of core facilities (time from solicitation to flight is approximately two years), investigations requiring experiment-unique equipment (time from solicitation to flight is more than two years), and small, rapid-response payloads (six months for payload integration).

An International Life Sciences Strategic Planning Working Group, including representatives of NASA, the European Space Agency, the Canadian Space Agency, the National Space Development Agency of Japan, the French space agency CNES, and the German space agency DARA, is working on collaborative plans for space station life sciences research.

Biomedical Monitoring and Countermeasures Program Manager Donald Stewart, Life Sciences Division, NASA Headquarters:

To study ways of combatting human physiological deconditioning in space, NASA is planning a Biomedical Monitoring and Countermeasures (BMAC) Program for Space Station Freedom. Space flights to date have not produced sufficient data to enable scientists to understand "the full extent of human risk associated with space flight"; hence, the BMAC Program is necessary if human missions in space are to last more than 16 days.

The BMAC Program will establish health and performance standards for human missions in space. Questions to be addressed by BMAC investigations include: what are the optimal biomedical monitoring scenarios? What changes might limit mission duration? Are there limits to the number of missions an individual can fly? What countermeasures are required, and when? Is there an optimum mission duration?

BMAC investigations will involve operational biomedical monitoring, functional monitoring, and risk assessments. Specific test protocols have not yet been determined. BMAC feasibility studies are complete, and design studies are about to begin. Four racks of hardware are planned for Space Station Freedom, offering opportunities "for rigorous involvement" of the science community.

Gravitational Biology Facility (GBF) Project Scientist Katherine Allen, NASA Ames Research Center:

NASA is developing a Gravitational Biology Facility (GBF) for Space Station Freedom comprising a set of generic laboratory equipment that will accommodate cell and developmental biology and plant biology experiments. This facility will be available as soon as Freedom is available for research. A Science Working Group (SWG) will identify equipment to be included in the GBF. The SWG also will identify design requirements for the facility so that it will meet the needs of researchers.

The GBF will accommodate a wide variety of species, several methods of observation, and many different methods of sample collection, preservation, and storage. Equipment for manipulating samples will include a compound microscope and radioisotope handling equipment. The GBF also will feature a small centrifuge for one-g control studies.
**Gas Grain Simulation Facility (GGSF)**

*Scientist Ken Greenwald, NASA Ames Research Center:*

A Gas Grain Simulation Facility (GGSF) being developed for Space Station Freedom will accommodate investigations of fundamental physical and chemical processes (nucleation, condensation, aggregation, etc.) involving suspended particles in the sub-micron to micron range. Such experiments are relevant to NASA studies of the origin and evolution of the solar system, the universe, and life therein. The GGSF also will accommodate experiments in other fields such as planetary science, astrophysics, and earth science.

Researchers have gone as far as they can on Earth with studies of the processes by which the solar system and the universe were formed. The microgravity environment of Space Station Freedom will increase particle suspension times, reduce interference from buoyancy-driven convection, and enable the study of gravitationally unstable objects and low-energy interactions that are masked by gravity.

The GGSF will offer investigators four experiment chambers and a broad variety of particle-generation and diagnostic methods. A current list of candidate GGSF experiments includes a Titan atmospheric aerosol simulation, a study of airborne bacteria in microgravity, and an investigation of planetary ring dynamics. The first GGSF science workshop took place this year; next year, NASA will hold a GGSF technology workshop and a second science workshop.

**Senior Scientist Glenn Funk, GE Government Services:**

The Centrifuge Facility Project (CFP) for Space Station Freedom will include a 2.5-meter-diameter centrifuge for plant and animal experiments at a range of 0.01 to 2.0 gs, modular habitats, and a glovebox for handling samples. The CFP will accommodate cardiopulmonary, musculoskeletal, neuroscience, plant biology, cell development, regulatory physiology, environmental health, radiation exposure, and behavior and performance investigations requiring long-duration exposures and the testing of multiple generations or space-adapted subjects.

The CFP will accommodate rats and mice and later will be upgraded to handle squirrel monkeys. Coriolis forces will render the one g to be generated by the space station centrifuge different from the one g here on Earth. NASA has considered a human-rated centrifuge but does not plan to build one at this time.

**Senior Research Associate John Tremor, Bionetics Corporation:**

A Controlled Ecological Life Support System (CELSS) Test Facility (CTF) being developed for Space Station Freedom will accommodate plant-growth experiments with a variety of food crops under carefully controlled environmental conditions (temperature, humidity, oxygen and carbon dioxide levels, light intensity).
The CTF will include two racks of equipment, one for experiments and one for support hardware such as nutrient delivery and condensate recovery systems. The productivity of plants in space is currently a major unknown.

A CTF science and technology working group has met three times since the fall of 1991. A NASA request for proposals (RFP) to build the CTF is due out in 1994, to be followed by a solicitation for investigations. Experiments will be selected and a CTF Investigators Working Group (IWG) formed by 1996.

Space Shuttle Payload Specialist Byron Lichtenberg (STS-9, the Spacelab 1 microgravity science mission of 1983, and STS-45, the Atlas 1 earth science mission in 1992):

Space Station Freedom researchers requiring crew support for their space investigations should keep several points in mind. Maintaining bioisolation is important. Including crew members as members of science teams, and involving them in preparations for flight investigations as early as possible, is also important.

Investigators also should note that, for now, life science investigations involving crew members as subjects are generally invasive activities; hence, the crew should know in advance exactly what is going to occur in space. Further, pre-flight and post-flight data collection is required, and crew members are very busy before a flight and very tired after a flight.

Crew time requirements for space-based experiments tend to double from the time plans are set to the time the investigations are conducted. Exact replicas of flight hardware are a necessity for pre-flight crew training. Science payloads requiring crew involvement should be designed so that crew members can observe experiments and access the hardware if repair or intervention is required.

Medical Operations Branch Chief Roger Billica, NASA Johnson Space Center:

NASA's plans for accommodating operational medicine on Freedom focus on a Crew Health Care System (CHECS) including a health maintenance facility, environmental health system, and exercise countermeasures facility. Space station operational medicine will involve establishing norms for humans in space, developing monitoring and countermeasures practices, gaining experience in remote health care (telemedicine), and operating as a test bed for crew health maintenance on the Moon and Mars.

NASA is looking for ideas in the field of space-station-era operational medicine research such as non-invasive health monitoring and diagnostic techniques, circadian shifting, telemedicine, decontamination strategies, extended-life pharmaceuticals, radiation protection, and crew selection. Radiation exposure is a major concern for long-duration human missions in space, and largely an unknown today.

Session 3: Technology Research

Session Co-chairman M. Frank Rose (Director, Space Power Institute, Auburn University):

Space Station Freedom will be an engineering experiment station, a laboratory for qualifying new technologies in the near term. No roadblocks based on physical laws stand in the way of using space. The only roadblocks are related to engineering and technology issues. For instance, high levels of space power will be required to support orbital operations in the future.

Space Station Freedom has great utility for space technology qualification, process development, in-space satellite repair, and materials engineering. Further, Freedom itself is an elaborate engineering experiment that
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will address space power, large space structures, and life support systems.

The planning cycle for space experiments has to be streamlined and made user friendly. The planning cycle for research access to Freedom must be reduced from the current five years down to one to three years. In addition, the cost of space transportation must come down ($500 per kilogram is a goal). Current space transportation costs vary depending on the accounting method used. However, Space Shuttle costs are quoted at up to $10,000 per kilogram.

To cut transportation costs NASA could pursue an aggressive development program for heavy lift launch vehicles and shift more payloads to lower cost expendable launch vehicles (ELVs). Another way to cut the cost of working in space would be to trim the amount of red tape and paperwork required to space-qualify experiments.

Session Co-chairman Roger Breckenridge (Deputy Manager, Space Station Freedom Office, NASA Langley Research Center): Reported on Precursor Space Station Experiments for Sherwin M. Beck. The Office of Aeronautics and Space Technology's (OAST) In-Space Technology Experiments Program (IN-STEP) is developing space station precursor investigations. IN-STEP experiments are small (fitting into a middeck locker or Get Away Special canister), low-cost (less than $5 million), and solicited by AO from NASA, industry and university researchers. Program performance to date shows a good trend — technology research is expanding and the planning cycle of flight experiments is accelerating. A 1992 IN-STEP AO is ready to be issued. OAST plans to accept approximately 50 Phase A proposals. These experiments should be ready for flight starting in 1997, using any suitable carrier, including Space Station Freedom. In fact, this AO is the first from OAST that shows Freedom as a carrier.

Professor Edward F. Crawley, Department of Aeronautics and Astronautics, Massachusetts Institute of Technology: The OAST-sponsored Middeck 0-g Dynamics Experiments (MODE) are an example of IN-STEP space station precursor research. The purpose of the MODE experiments, flown on the Space Shuttle, was to conduct engineering research that would promote technology development for space applications. Researchers must have a clear idea of why the space environment is necessary to conduct their experiments. Many years of ground test work culminated in a one and one half day experiment in orbit. The MODE experiments produced valuable engineering data on technology issues that industry researchers had not previously considered.

The MODE flight experiments used a structural test article (STA) and a fluids test article (FTA) — scaled-down hardware that cost a fraction of the price for full-scale items. Doing the research in scale and then using scaling laws to interpret the data was very effective. The STA experiment, a scaled-down section of a generic space truss structure, was assembled and conducted in the shuttle middeck. Space Station Freedom will be able to accommodate larger test articles.

Lessons learned from the IN-STEP Program are that low cost experiments are possible; integrating a space experiment is an art, not a science; the flight crew can be an important part of an experiment's success if properly trained (the crew needs as much hardware interaction during training as possible); and investigators need to become familiar with real-time operations before their experiments fly.

Current estimates for crew time available for space station experiments are based on 100 percent utilization of all available payload.
racks. It is likely that Freedom will carry substantially fewer than the maximum number of experiments in its early phases. Crew time allocations are still "to be determined."

Technology Experiments Manager Don Avery, Space Station Utilization Office, NASA Langley Research Center:
The proposed traffic model for Space Station Freedom includes categories for attached and pressurized technology payloads, for Freedom itself as an instrumented experiment test article, and for a guest investigator program enabling researchers to use data from existing experiments and space station subsystem instruments.

In planning space station attached-payload experiments, technology researchers should consider the following design issues: environment, carrier, payload accommodations, and integration. Investigators will be assisted in designing technology payloads by a technical interchange process that includes space station subsystem and utilization experts. Solid object modeling and animation techniques are being employed early in the design of attached payloads to identify problems during the conceptual phase.

Designers of attached payload experiments should assume robotic installation with contingency plans for extravehicular activity (EVA). EVA capability will be available, but it is very time consuming and expensive. A Mobile Transporter will be used to manipulate external payloads. Because Mobile Transporter operations will affect the space station microgravity environment, they will be scheduled to minimize disturbances.

Technology researchers interested in flying experiments on Space Station Freedom can contact Langley Research Center's Space Station Utilization Office during the conceptual stages of a Phase A proposal. OAST AOs are open to U.S. researchers only. However, the international partners in Space Station Freedom will be cooperating on many investigations.

Raymond Kvaternik, Spacecraft Dynamics Branch, Structural Dynamics Division, NASA Langley Research Center:
A Modal Identification Experiment (MIE) being developed by OAST will use Space Station Freedom itself as a test article for a large space structure investigation. This experiment also will contribute to on-orbit space station verification.

The MIE will provide the first opportunity to obtain vibration data for the fully assembled space station structure, which is too large and flexible to be tested as a single unit on the ground. MIE researchers have conducted extensive simulations of on-orbit tests, as well as exploratory laboratory simulations using small-scale models, to evaluate potential performance.

Richard DeLombard, In-Space Technology Experiments Program, NASA Lewis Research Center:
The Tank Pressure Control Experiment (TPCE) is an OAST-sponsored cryogenic fluid dynamics investigation that will yield information useful to the design and operation of future onboard cryogenic fluid storage systems. The Thermal Energy Storage Flight Project (TES) is an OAST-funded thermal management experiment that will aid in the design of solar dynamic power systems.

OAST's Solar Array Module Plasma Interaction Experiment (SAMPLE) will determine the environmental effects of low Earth orbit on solar cells. SAMPLE will provide information necessary for optimum module design. A Vibration Isolation Advanced Technology
Development initiative funded by OSSA will provide the technology necessary to maintain a stable microgravity environment for sensitive payloads on spacecraft.

The OSSA-funded Space Acceleration Measurement System (SAMS) is an instrument designed to measure the microgravity acceleration environment for Space Shuttle and space station payloads. The SAMS has cost $12 million from concept definition to on-orbit use in the Shuttle middeck. This instrument will be used on Space Station Freedom.

Technology Experiments Manager Don Avery, Space Station Utilization Office, NASA Langley Research Center:
Long-term exposure in low Earth orbit can enhance our understanding of what might happen to materials and coatings used on extended space missions. The results of materials exposure experiments flown on NASA's Long-Duration Exposure Facility (LDEF) are already being applied to space station design.

Long-duration exposures on Space Station Freedom will further benefit spacecraft materials and coatings research. Current plans call for materials exposure experiments to be launched with the first space station element.

David Allen, Center on Materials for Space Structures, Case Western Reserve University:
The Center on Materials for Space Structures, a NASA-cosponsored CCDS, is working on long-duration space materials exposure experiments intended to evaluate new materials for space structures and develop passive and active facilities for materials exposure and analysis in space. A major facility for materials exposure is planned for mounting on the space station truss structure.

Samples will be rotated once a year, allowing commercial researchers to obtain information promptly on materials survivability in the low Earth orbit environment. The space station environment will not necessarily be pristine; hence, the results of these experiments may be different from those flown on the LDEF. This 30-year research program will provide information on how to manage the environment around a space station structure.

Theodore Swanson, Advanced Development and Flight Experiment Section, NASA Goddard Space Flight Center:
The biggest differences between ground- and space-based tests show up with fluids systems, especially two-phase flow systems. Generic microgravity fluids research is needed to create a database from which researchers can develop reliable analytical models of fluid behavior in space. Space Station Freedom will support high-quality heat transfer experiments and long-term data collection.

Several new capabilities will be available to fluids researchers on Freedom. The microgravity environment will simplify experiments because most nonlinearities in fluid behavior are attributable to Earth's gravity. Fluids in space should exhibit linear behavior that will enable the development of new models.

Researchers must take into account the steady state accelerations that will occur on Freedom (10^{-5} to 10^{-6} gs) in designing fluids experiments. In addition, space station safety concerns will limit the use of fluids and require safety features in experimental hardware.

Matthew Kolodney, Lockheed Corporation:
Optimal design of spacecraft environmental control and life support systems (ECLSS) for long-duration missions requires an understanding of microgravity and its long-term influence on system performance. Short-
duration testing on KC-135 or Space Shuttle flights is not sufficient. Hence, experiments are planned for Space Station Freedom to study fundamental processes associated with air and water recycling in microgravity. Long term testing of life support hardware under microgravity conditions is required as well.

Jim Scheib, McDonnell Douglas: Space Station Freedom’s truss structure will feature four sites for external attached payloads. Volume limits for attached payloads are usually not physical but related to performance parameters such as antenna viewing requirements. Payload sponsors must provide their own thermal control. Payload thermal analysis will be time and site dependent. Investigators will have to provide their own structural support for space station external payloads.

Although attached payload Site 1 is located next to the U.S. laboratory module, lab venting should not pose problems for experiments there. Venting contamination from Space Shuttle docking will be a significantly greater hazard to external payloads than allowable limits from the lab module. External payload sites can be covered during Shuttle maneuvers, but venting from the lab module cannot be predicted.

Pointing and viewing capabilities at attached payload sites are passive; no pointing capability is provided. Therefore, experiment designers will have to provide their own pointing if required. Potential interference with communications antennas or solar or radiator arrays will be evaluated on a case by case basis. Interference with space station subsystem viewing requirements will not be allowed. Site viewing angle measurements are not yet approved for release to investigators.

Session 3: Microgravity Research and Biotechnology

Session Co-chairman Robert Bayuzick, Vanderbilt University (former Visiting Senior Scientist, Microgravity Science and Applications Division, NASA Headquarters): NASA’s microgravity science program has two elements: the Microgravity Science and Applications Division, which sponsors basic and applied research, and the Office of Commercial Programs, which sponsors flight projects that will stimulate private sector involvement and investment in space. The two programs share flight hardware and cooperate on some research initiatives. Many space station precursor experiments are being planned to prepare for microgravity research on Space Station Freedom.

The goal of NASA’s microgravity research program is to study fluid science, combustion science, materials science, biotechnology, and fundamental physics for the purpose of attaining a structured understanding of gravity-dependent phenomena and physical phenomena usually masked by the effects of gravity. In short, this field of research uses gravity (or the absence of it) as an experimental parameter.

Plans for space station based microgravity research facilities include Spacelab to space station transition hardware as well as hardware designed specifically for Space Station Freedom. The Microgravity Science and Applications Division also will offer flight opportunities for small and rapid response payloads that will allow researchers to get experiments aboard Space Station Freedom in two years. The division periodically will release NASA Research Announcements (NRAs) to solicit new experiment proposals.
The division is sponsoring the development of major microgravity research hardware for Space Station Freedom: an Advanced Protein Crystal Growth Facility, Space Station Furnace Facility, Modular Combustion Facility, Fluid Physics Dynamics Facility, Modular Containerless Processing Facility, and Biotechnology Facility. A glovebox will be available for crew handling of research samples.

A payload adapter may be available to accommodate small- to moderate-scale microgravity experiments. NASA will begin operating microgravity research facilities during space station assembly (crew tended capability). NASA’s research program will involve significant collaboration with the international science community through the sharing of research facilities.

Access to space for microgravity researchers is growing, with a heavy load of flight activity planned for the coming decade. Space Station Freedom’s research accommodations will surpass those of all other space research facilities, particularly in the areas of power and available pressurized experiment volume.

_NASA Microgravity Combustion Discipline Working Group Chairman Gerard Faeth (University of Michigan, Department of Aerospace Engineering):_

Combustion science is relevant to the study of pollution, energy utilization, waste incineration, power and propulsion systems, and fire and explosion hazards, among other things. The implications of microgravity combustion experimentation are as important as the development of computers and optical diagnostics. Gravity has impeded fundamental understanding of combustion more than most areas of science; therefore, access to microgravity should yield major breakthroughs.

Microgravity eliminates the effects of buoyancy on combustion; scientists have never observed some of the most fundamental combustion phenomena without substantial buoyancy disturbances. Buoyancy inhibits research relating to propagating flames, motionless flames, flammability limits, flame spread along solid surfaces, convecting flames, convection drop combustion and turbulent combustion. This problem stands in the way of a rational merging of theory, in which buoyancy is of little interest, and experimentation, which always is contaminated by buoyancy.

_NASA-sponsored microgravity combustion investigations are using both ground- and space-based facilities. Experiments planned for space-based facilities involve laminar premixed flames, soot processes in laminar jet diffusion flames, the structure of laminar and turbulent jet diffusion flames, solid surface combustion, one-dimensional smoldering, ignition and flame spread of liquids, drop combustion, and the quenching of particle-air flames._

Combustion research in orbit is important for spacecraft fire safety because the microgravity environment can introduce new fire and explosion hazards that have no counterpart on earth. No fire-safe atmospheres have been provided on spacecraft as yet. Microgravity broadens flammability limits, creates novel regimes of flame spread, enhances flame radiation effects, slows down fire detector response, and enhances combustion upon injecting fire extinguishing agents.
On the other hand, the controlled environment of a spacecraft can offer a fire-safe atmosphere. Investigation of these problems is just beginning, with fire safety experiments supplementing fundamental combustion experiments. It is possible that fire hazards in space can be entirely eliminated, but not in the near term because of systems complications and a lack of understanding regarding human response to such an environment.

**Fluids Science Program Scientist Bradley Carpenter, Microgravity Science and Applications Division, NASA Headquarters:**

NASA's microgravity fluids science program currently supports research in multi-phase flows and heat transfers, behavior of granular media and colloids, interface dynamics, morphological stability, and contact line phenomena. Advances in these areas will enhance understanding of materials processing in space and on Earth and contribute to diverse technologies such as oil and chemical extraction.

Air rises above flowing water on Earth (top); in microgravity, air bubbles remain mixed with the liquid (bottom).

NASA's Fluid Physics Dynamics Facility will be the primary platform for microgravity fluid physics on Space Station Freedom. Experiment-unique equipment will be changed out once a year. NASA is evaluating 207 proposals received in response to fluid physics research announcements. NASA will fund experiments in six research areas: capillary phenomena, multiphase flow and heat transfer, diffusive transport, magneto/electrohydrodynamics, colloids and nucleation phenomena, and solid-fluid interface; 40 to 50 proposals will likely be funded. Additional solicitations will be issued for flight and ground-based research proposals.

**NASA Materials Science Discipline Working Group Chairman John Perepezko (University of Wisconsin-Madison):**

The goals of materials science research in microgravity are to understand relationships between materials microstructure and properties during processing and to apply process modeling and advanced processing concepts toward achieving designed microstructures.

The objective is to use microgravity to advance understanding of materials processing, including phase transformations during solidification and deposition, transport phenomena, and structure-property relationships. Technological applications of microgravity materials science include containerless processing, directional solidification and crystal growth, and casting.

Extended-duration space flights offer new opportunities to control the microstructure, processing, and properties of materials. First, minimizing gravitational effects reduces buoyancy-driven convection. Flows caused by density differences, due to composition or temperature gradients, will then be reduced or eliminated, permitting more precise control of the temperature and the composition of a melt (critical to achieving high-quality crystal growth of electronic materials or alloys).

Operating in microgravity will facilitate containerless processing by doing away with the limitations of containment for reactive melts. Non-contacting electromagnetic, electrostatic, or acoustic fields can be used to position samples. Containerless processing minimizes contamination, enabling the study of reactive melts and eliminating extraneous crystal nucleation so that novel crystalline structures and new glass compositions may be produced.

To take full advantage of the microgravity environment, materials researchers will need reliable processing models based on sound ground-based experimental experience and established thermophysical property data.
Biophysics Branch Chief Daniel Carter, NASA Marshall Space Flight Center:
NASA's biotechnology program uses the microgravity environment to investigate bioprocessing phenomena. The program currently supports research in the areas of crystal growth of biological macro-molecules and cell and molecular science. In the latter area, research on tissue cultures is under way at NASA's Johnson Space Center, using bioreactors for processing.

One objective of protein crystal growth research in space is to identify optimal conditions for nucleating and growing crystals. Another objective is to identify optimal methods of manipulating crystals in microgravity. By determining the structure of protein crystals, scientists may be able to develop dramatically improved medical and agricultural products. It can take up to three months to grow a protein crystal in space, due to slow growth or delayed initiation of growth.

Long-duration experiments on Space Station Freedom will enable researchers to learn more about optimum mixing times and solution concentrations. Longer periods on orbit can be beneficial because scientists cannot predict how long it will take to grow a particular crystal. Several crystal structures grown in Space Shuttle experiments have been refined to significantly higher resolution than obtainable on the ground.

Session Co-chairman Jim Fountain (Program Manager, Commercial Use of Space Station Freedom, Office of Commercial Programs, NASA Headquarters):
OCP-sponsored investigations use a variety of flight hardware and transportation methods for gaining microgravity experience. Experiment carriers range from KC-135 aircraft and sounding rockets to the Space Shuttle, giving researchers the flexibility to vary payload complexity and cost. OCP has sponsored the building of 32 payload hardware elements that have flown in space a total of 73 times.

In 1993, two new capabilities will be available to accommodate microgravity experiments. COMET, a recoverable experiment capsule to be launched by expendable launch vehicle, can keep experiments in orbit for extended periods; and Spacehab, a pressurized module, will expand the Shuttle's middeck payload accommodations. In addition, OCP is supporting the development of a Wakeshield Vacuum Facility by Space Industries Inc. and the University of Houston's Center for the Commercial Development of Space. OCP is planning a number of space station experiments for launching in 1996 and 1997.

Commercial Development Associate Director Marianna Long, Center for Macromolecular Crystallography (University of Alabama in Birmingham):
The Center for Macromolecular Crystallography (CMC) is sponsoring research into the large-scale crystallization of proteins in microgravity via temperature change. The major objective is temperature-driven growth of protein crystals in large batches in the microgravity environment. Another objective is to use temperature to initiate and control protein crystal growth. The results of this
research may be beneficial in developing pharmaceutical products such as human insulin, human growth hormone, interferons, and tissue plasminogen activator.

Crystal growth can proceed unhindered in microgravity due to lack of surface effects. Initiating protein crystal growth via temperature enables dynamic control and eliminates the need for seeding. Because crystallization is also a procedure for purifying organic materials, microgravity crystallization could be used to remove trace impurities from high-value protein pharmaceutical products.

In two insulin-crystal-growth experiments using a Protein Crystal Growth Facility (PCF) on the Space Shuttle, the hardware performed perfectly, and many crystals were produced that were much larger than ground-grown controls. Crystal size was a function of container volume. X-ray analysis showed that the bigger space-grown insulin crystals diffracted to higher resolution than their ground controls. When the data were normalized for size, they still indicated that the space crystals were better than the ground crystals. Researchers do not yet know why crystal size is linked to container or whether the temperature gradient within a container affects crystal size.

The CCR’s bioseparations program offers industry access to continuous flow electrophoresis and aqueous two-phase partitioning in space. This program is the first to include ground-based mathematical modeling services that enable preflight evaluations of performance. The center’s illumination studies program aims to develop photometric equipment for biological experimentation and lighting for space- and ground-based biological experiments.

Through its commercial partner program, the CCR offers access to flight, experiment planning and post-fight analysis, payload integration, and mission management, as well as expertise in intellectual property agreements. The CCR is working with Genentech Inc. on the first commercial physiological experiment to be flown in space; it will measure the effects of microgravity on a number of proteins.

The center is developing equipment to accommodate experiments on sounding rocket and COMET missions. A robotic minilab called the Penn State Biomodule, developed for cellular and crystal growth studies, will be launched on a CONSORT sounding rocket. In addition, Penn State is working with a CCR industry affiliate, Corabi International Telemetrics, to market a telepathology instrument for long distance transmission and control of microscope images. The instrument is also being developed for use on Space Station Freedom.

Director Charles Lundquist, Consortium for Materials Development in Space: The Consortium for Materials Development in Space (CDMS) focuses on commercial materials development projects that benefit from the unique attributes of space and rely on innovative applications of physical chemistry and materials transport and their interactions. In addition to sponsoring research, the Consortium is also developing space processing.
equipment, launch vehicles for access to space, and hardware and techniques to measure spacecraft environments.

The Sintered and Alloyed Materials Project is a CMDS initiative that could benefit from operating on Space Station Freedom. Two furnace systems are candidates for this project: the Space Experiment Facility and the Equipment for Controlled Liquid Phase Sintering Experiment (ECLiPSE). Hardware could be left on orbit for extended periods of time.

However, crew interaction with such equipment could be valuable; the carrier for the ECLiPSE will be compatible with Spacehab, Freedom, and other systems. Other hardware being developed by the CDMS that is of potential interest to space station researchers includes accelerometer systems and atomic oxygen flux measurement systems.

Materials Dispersion and Biodynamics
Manager Marian Lewis, Consortium for Materials Development in Space:
The CMDS’s Materials Dispersion and Biodynamics Project (MDBP) focuses on the dispersion and mixing of various biological materials and the dynamics of cell-to-cell communication and intracellular molecular trafficking in microgravity. Research encompassed by this project includes biomedicine, cell biology, biotechnology, protein crystal growth, ecological life support (involving algae and bacteria), drug delivery, biofilm deposition by living organisms, and hardware development to support living cells on Space Station Freedom.

MDBP experiments will be launched on sounding rockets, the Space Shuttle, and COMET capsules. Ultimately, larger-scale commercial operations will be launched on Space Station Freedom. The consortium is working to inform prospective space station researchers about potential commercial medical applications of microgravity research and to solicit involvement in the consortium’s activities.

The objectives of the MDBP are to raise private-sector awareness of the research potential of space, facilitate private-sector development of hardware for microgravity research, and develop cell cultures, crystals, and processes in space that will yield commercial products. The project is a collaboration among industry, university and government researchers. The consortium is contacting potential researchers in the biotechnology and pharmaceutical industries.

Project Manager, Barbara Heizer, Crystals by Vapor Transport Experiment (CVTE) and Space Experiment Facility (SEF), Boeing Aerospace Corporation:
The Crystals by Vapor Transport Experiment (CVTE) and Space Experiment Facility (SEF) are materials processing facilities built for use on the Space Shuttle middeck. Boeing is pursuing these projects because space systems are a major Boeing product area, materials processing is a prime element of commercial space activities, and potential markets exist for space materials processing facilities.

The CVTE, which took six years to develop, is scheduled to fly on the Space Shuttle in October 1992, under a Joint Endeavor Agreement between NASA and Boeing. Boeing is building the SEF under a contract with the Center for Macromolecular Crystallography at the University of Huntsville; it is designed to fly on an early Spacehab mission, and it is currently undergoing environmental testing.

Boeing took the following steps in developing these projects: development of cooperative agreements with researchers, selection of
appropriate vapor transport crystal growth process, identification of candidate materials for space processing, and design and development of hardware.

It is vital to name a chief scientist early for a project like the CVTE. The chief scientist develops an experiment plan that will shape hardware and software design, runs ground and flight research, and interfaces with the scientific community. The Chief Scientist must have authority equal to that of the Chief Engineer. A Mission Manager is needed to represent the payload through integration and serve as an advocate.

Investigators should get involved in the process early to ensure that their experiments are compatible with ground and flight hardware. Time must be allowed for confidence building between investigators and the resident science and engineering team. All parties must be prepared to compromise and recognize that the experiment flown may differ from the original concept because of incompatible requirements.

**Session 4: Closing Plenary**

The final session of the conference began with reports on discussions in the previous day's splinter sessions, delivered by session chairpeople (see above) and closed with presentations by an astronaut who is a veteran of three Space Shuttle missions and a staff representative of the NASA authorization committee on the U.S. House of Representatives.

Questions that arose during the splinter sessions and throughout the plenary sessions included: How much funding will be available to researchers? How many years of funding will NASA provide for a single research project? Will crew activities on Freedom disturb the stable microgravity environment required for certain types of experiments? Will investigators have a role in choosing the crew members who will work on their experiments? How can researchers ensure that they are informed of NASA research opportunities?

NASA officials explained that funding for space research varies from year to year and project to project; proposals are usually funded for no more than two years. It does not appear that crew activities will affect the microgravity environment on Freedom, but NASA is still studying the issue. Investigators will have a say in crew assignments for space station research projects. To ensure that they are informed of all upcoming NASA research opportunities, researchers should give their names and addresses to NASA to be added to a mailing list. (See inside back cover for contacts.)

**NASA Astronaut Bonnie Dunbar (crew member, Space Shuttle mission USML 1):**

Space Shuttle crews train for 18 months per mission; they are assigned to science missions according to their background. Training encompasses preparations for troubleshooting. Astronauts often need to make judgment calls about how investigations will proceed in space; they want to work with investigators on preparing payloads and planning science operations so they will be as familiar as possible with the experiment.

"We're here to serve you.... We're your heads, eyes, and ears in orbit."

The astronaut office at Johnson Space Center has organized an ad hoc science support group to keep abreast of the state of the art in science. The activities of this group support the work of the astronaut office's mission development group.

Astronauts are already testing space station precursor hardware on Space Shuttle missions, including two types of gloveboxes, and studying onboard vibration disturbances. Thus far, vibration caused by crew exercise has been indistinguishable from the background vibration of 5-10 micro-gs.

**Science Advisor Richard Obermann, Subcommittee on Space, House Committee on Science, Space, and Technology:**

Thus far, Congress has not approved the transfer of funds allotted for defense to the Government's discretionary spending account, from which NASA's budget comes. Thus, with budget deficit reduction a pressing need, increasing funds for one discretionary program (such as NASA) requires cutting funds for another.
NASA's Fiscal Year 1993 budget request is "a modest one" — 4.8 percent accounting for inflation. But Congress likely will approve a FY 93 NASA budget that is 1-5 percent less than NASA's FY 92 budget. With regard to Space Station Freedom, Congress has two major concerns. First, NASA must make Freedom as accessible as possible to all prospective researchers. Second, NASA must structure space station operations in a way that minimizes costs over the project's 30-year life. ✿
SESSION 1: Monday, August 3

Welcome Lunch
- Welcoming Remarks
  Jack Lee, Director, NASA Marshall Space Flight Center

Space Station Freedom Overview and Research Capabilities
- Introduction to Space Station Freedom
  Richard Kohrs, Director, Space Station Freedom (SSF), NASA Office of Space Systems Development
- Space Station Freedom Research Capabilities
  Robert W. Moorehead, Deputy Director, Space Station Freedom Program and Operations, NASA Office of Space Systems Development
- Opportunities for Research on Space Station Freedom
  Dr. Robert W. Phillips, Chief Scientist, Space Station Freedom, NASA Office of Space Systems Development
- How To Get On Board Space Station Freedom
  Dr. John-David Bartoe, Director, User Integration, Spacelab/Space Station Utilization, NASA Office of Space Flight

SESSION 2: Tuesday, August 4

Space Station Freedom Research Plans and Opportunities
- Commercial Research Plans and Opportunities
  Ray J. Arnold, Deputy Assistant Administrator, NASA Office of Commercial Programs
- Space Technology Research Plans
  W. Ray Hook, NASA Office of Aeronautics and Space Technology, (Director for Space, NASA LaRC)
- OSSA Space Station Freedom Science Utilization Plans
  Dr. Philip J. Cressy, Chief, Space Station Utilization Branch, NASA Office of Space Science and Applications (OSSA)
- Commercial Researcher Perspective
  Dr. Larry DeLucas, Associate Director, Protein Crystal Growth, University of Alabama at Birmingham, Center for Macromolecular Crystallography
- Japanese Plan for Space Station Freedom Utilization
  Toshio Mizuno, Deputy Director of the Space Station Program, National Space Development Agency of Japan
- Canadian Space Agency Research Plans
  James Faulkner, Manager, Space Station Operations and Utilization, Canadian Space Agency
**Space Station Freedom Utilization Conference**

- European Research Plans
  Jean-Jacques Dordain, Head of Microgravity and Columbus Utilization Department, European Space Agency

- Space Life Sciences Perspectives for Space Station Freedom
  Dr. Laurence R. Young, Professor of Aeronautics and Astronautics, MIT and Payload Specialist in Training, Spacelab Life Sciences Mission 2

- Research Experiences on Materials Science in Space Aboard Salyut and Mir
  Dr. Liya L. Regel, Director, International Center for Gravity Materials Science and Applications, Clarkson University (Former Head, Materials Science Department, Institute for Space Research, USSR Academy of Sciences)

**Keynote Address**
- Daniel S. Goldin, NASA Administrator

**SESSION 3: Wednesday, August 5**

**Life Sciences Research on Space Station Freedom**

- Life Sciences Utilization of Space Station Freedom
  Lawrence Chambers, Manager, Space Station Life Sciences Program, NASA Office of Space Science and Applications

- Life Sciences Recruitment Objectives
  Dr. J. Richard Keefe, Program Scientist, Space Station Life Sciences Program, NASA Office of Space Science and Applications

- Biomedical Monitoring and Countermeasures Facility
  Donald F. Stewart, M.D., Manager, BMAC, NASA Office of Space Science and Applications

- Gravitational Biology Facility on Space Station Freedom
  Katherine Allen, Project Bioengineer, NASA Ames Research Center

- Gas Grain Simulation Facility
  Dr. Ken Greenwald, Facility Scientist, NASA Ames Research Center

- Research Opportunities with the Centrifuge Facility
  Dr. Glenn Funk, Senior Scientist, NASA Ames Research Center

- CELSS Test Facility
  Dr. Robert MacElroy, Project Manager, NASA Ames Research Center
  (Presented by Dr. John Tremor)

- An On-Orbit Viewpoint of Life Sciences Research
  Byron Lichtenberg, former NASA Payload Specialist Astronaut and Life Sciences Researcher

- Crew Health
  Dr. Roger D. Billica, Chief, Medical Operations Branch, NASA Johnson Space Center
Technology Research on Space Station Freedom

- Space Station Freedom as an Engineering Experiment Station
  Dr. M. Frank Rose, Director, Space Power Institute, Auburn University

- Precursor Space Station Freedom Experiments
  (Presented by Dr. Roger A. Breckenridge)

- Middeck 0-gravity Dynamics Experiment (MODE)
  Professor Edward F. Crawley, Department of Aeronautics and Astronautics, MIT

- Utilization of Space Station Freedom for Technology Research
  Don E. Avery, Space Station Utilization Office, Space Station Freedom Office, NASA LaRC

- Modal Identification Experiment
  Raymond G. Kvaternik, Spacecraft Dynamics Branch, Structural Dynamics Division, NASA LaRC

- Experiment Activities in Support of Space Station Freedom
  Richard DeLombard, In-Space Technology Experiments, NASA LaRC

- Spacecraft Materials and Coatings Experiments
  Wayne S. Slemp, Senior Researcher, Materials Division, NASA LaRC
  (Presented by Don E. Avery)

- Long Duration Space Materials Exposure (LDSE)
  David Allen (Allen Aerospace), Center for Materials and Structure, Case Western Reserve University

- Potential Pressurized Payloads; Fluid and Thermal Experiments
  Theodore D. Swanson, Advanced Development and Flight Experiment Section, NASA Goddard Space Flight Center

- 0-gravity Life Support for Space Station Freedom
  Matthew Kolodney, Lockheed Corporation

- Space Station Freedom Attached Payload Accommodations
  Jim Scheib, McDonnell Douglas Corporation

Microgravity Research and Biotechnology on Space Station Freedom

- Research Objectives, Opportunities and Facilities
  Dr. Robert Bayuzick, Visiting Senior Scientist, Department of Material Science, Vanderbilt University on Sabbatical to Microgravity Sciences and Applications Division, NASA Office of Space Science and Applications

- Combustion Research
  Professor Gerard Faeth, Department of Aerospace Engineering, University of Michigan, Chairman of the Combustion Discipline Working Group

- Microgravity Fluid Physics Research
  Dr. Bradley Carpenter, Program Scientist, Microgravity Sciences and Applications, NASA Office of Space Sciences and Applications
SPACE STATION FREEDOM UTILIZATION CONFERENCE

- Materials Science Research in Microgravity
  Professor John H. Perepezko, Department of Metallurgical and Materials Engineering, University of Wisconsin, Chairman of the Materials Science Discipline Working Group

- Protein Crystal Growth
  Dr. Daniel Carter, Chief of Biophysics Branch, NASA Marshall Space Flight Center, Vice Chairman of the Biotechnology Discipline Working Group

- Office of Commercial Programs' Research Activities
  James Fountain, Program Manager, Commercial Utilization of Space Station Freedom, NASA Office of Commercial Programs

- Large Scale Crystallization of Protein Pharmaceuticals in Microgravity via Temperature Change
  Dr. Marianna Long, Associate Director, Commercial Development, Center for Macromolecular Crystallography

- Commercial Opportunities in Bioseparations and Physiological Testing Aboard Space Station Freedom
  Dr. Wesley Hymer, Director, Center for Cell Research

- Consortium for Materials Development in Space (CMDS)
  Dr. Charles Lundquist, Director, Consortium for Materials Development in Space (CMDS)

- Materials Dispersion and Biodynamics Project Research
  Dr. Marian Lewis, Manager of Materials Dispersion and Biodynamics, CMDS

- Space Experiments Facility and Crystals by Vapor Transport Experiment
  Barbara Heizer, Project Manager, Boeing Aerospace Corporation

SESSION 4: Thursday, August 6

Closing Plenary

- A Congressional Perspective on the Space Station Program
  Dr. Richard Obermann, Science Advisor, Space Subcommittee, Committee on Science, Space and Technology, U.S. House of Representatives

- Crew Experience in Space Research
  Bonnie J. Dunbar, Mission Specialist - Payload Commander for the U.S. Microgravity Laboratory

- Open Forum with Audience Participation on Selected Issues and Topics
  Dr. Robert Bayuzick, Dr. Judith Ambrus, Lawrence Chambers and James Fountain

- Closing Remarks
  Dr. John-David Bartoe
SESSION 1:
OVERVIEW AND RESEARCH CAPABILITIES
SPACE STATION FREEDOM UTILIZATION CONFERENCE

AUGUST 3, 1992
INTRODUCTION TO SPACE STATION FREEDOM

Presented by Richard Kohrs
NASA Office of Space Systems Development
NASA Headquarters

ABSTRACT

NASA field centers and contractors are organized to develop “work packages” for Space Station Freedom. Marshall Space Flight Center and Boeing are building the U.S. laboratory and habitation modules, nodes, and environmental control and life support system; Johnson Space Center and McDonnell Douglas are responsible for truss structure, data management, propulsion systems, thermal control, and communications and guidance; Lewis Research Center and Rocketdyne are developing the power system. The Canadian Space Agency (CSA) is contributing a Mobile Servicing Center, Special Dextrous Manipulator, and Mobile Servicing Center Maintenance Depot. The National Space Development Agency of Japan (NASDA) is contributing a Japanese Experiment Module (JEM), which includes a pressurized module, logistics module, and exposed experiment facility. The European Space Agency (ESA) is contributing the Columbus laboratory module.

NASA ground facilities, now in various stages of development to support Space Station Freedom, include: Marshall Space Flight Center’s Payload Operations Integration Center and Payload Training Complex (Alabama), Johnson Space Center’s Space Station Control Center and Space Station Training Facility (Texas), Lewis Research Center’s Power System Facility (Ohio), and Kennedy Space Center’s Space Station Processing Facility (Florida).

Budget appropriations impact the development of the Space Station. In Fiscal Year 1988, Congress appropriated only half of the funds that NASA requested for the space station program ($393 million vs. $767 million). In FY 89, NASA sought $967 million for the program, and Congress appropriated $900 million. NASA’s FY 90 request was $2.05 billion compared to an appropriation of $1.75 billion; the FY 91 request was $2.45 billion, and the appropriation was $1.9 billion.

After NASA restructured the Space Station Freedom program in response to directions from Congress, the agency’s full budget request of $2.029 billion for Space Station Freedom in FY 92 was appropriated. For FY 93, NASA is seeking $2.25 billion for the program; the planned budget for FY 94 is $2.5 billion. Further alterations to the hardware configuration for Freedom would be a serious setback; NASA intends “to stick with the current baseline” and continue planning for utilization.
SPACE STATION FREEDOM
Great Nations Dare To Explore

It's Time For America To Take Its Place On The Final Frontier

SPACE STATION FREEDOM
PERMANENTLY MANNED CONFIGURATION

EUROPEAN SPACE AGENCY (ESA) ELEMENTS:
- Pressurized Laboratory Module
- Man-Tended Free Flyer (MTFF)

JAPAN (NASDA) ELEMENTS:
- Pressurized Laboratory Module
- Exposed Facility
- Experiment Logistics Module

CANADA (CSA) ELEMENTS:
- Mobile Servicing Center (MSC)
- Special Dexterous Manipulator (SDM)
- MSC Maintenance Depot (MMD)

NASARJOHNSON (Texas) ELEMENTS:
- Integrated Truss Segments
- Mobile Transporter
- Airlock

NASAMARSHALL (Alabama) ELEMENTS:
- Pressurized Shells For Nodes
- Habituation Module
- Laboratory Module
- Logistics Modules (Press & Unpress)

SYSTEMS:
- ECLS
- Internal Thermal Control
- Internal Audio & Video
- Man Systems Equipment

* UNDER A SEPARATE BILATERAL AGREEMENT, ITALY IS PROVIDING TWO MINI PRESSURIZED LOGISTICS MODULES
SPACE STATION FREEDOM
GROUND FACILITIES

**Marshall**
Payload Operations Integration Center
- Payload control
- Mission management
- Science operations and integration
- Engineering Support Center for MSFC

**Johnson**
Space Station Control Center
- Command and control of operations
- Operations planning and analysis
- Systems monitoring and data processing
- Voice communications and video processing
- Orbit determination and planning

**Lewis**
Power System Facility
- Development testing of
  Power system components and model software
  Reliability tests
  Test facilities
  Troubleshooting power and control systems
- Analysis of electrical power system in orbit

**Kennedy**
Space Station Processing Facility
- Prelaunch/launch processing of non hazardous components and supplies
- Receipt, inspection, verification of hardware
- Preparation of elements, experiments, launch packages
- Final testing prior to launch
- Element turnaround and resupply operations

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**Budget Comparisons**

Total Program Budget Authority (RY$M)

- **FY 1985**
  - Budget submitted to Congress: $150
  - Actual Appropriation: $155

- **FY 1986**
  - Budget submitted to Congress: $230
  - Actual Appropriation: $200

- **FY 1987**
  - Budget submitted to Congress: $410
  - Actual Appropriation: $420

- **FY 1988**
  - Budget submitted to Congress: $383
  - Actual Appropriation: $767

- **FY 1989**
  - Budget submitted to Congress: $967
  - Actual Appropriation: $900

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**Budget Summary**

- **FY 1990**
  - Actual Appropriation: $2050

- **FY 1991**
  - Actual Appropriation: $1750

- **FY 1992**
  - Actual Appropriation: $1900

- **FY 1993**
  - Actual Appropriation: $2029

- **FY 1994**
  - Actual Appropriation: $2250

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**FISCAL YEAR**
NASA's plan for enhancing space-based research capabilities begins with extended-duration Space Shuttle missions that will double the research capability currently provided by Spacelab and culminate in Space Station Freedom. The 14-day USML 1 mission flown on the Space Shuttle in June 1992 was a space station precursor mission, dedicated to microgravity and life science research.

Freedom will be a permanent space-based research facility, providing a working environment nearly free of buoyancy-driven convection, sedimentation, and hydrostatic pressure and featuring access to the ultra-high vacuum of space (for external payloads). In its crew-tended phase, Space Station Freedom will provide 40 times Spacelab's capability, and in its permanently occupied phase, Freedom will provide 110 times Spacelab's capability. (The Russian space station, Mir, offers 26 times Spacelab's capabilities.)

According to NASA's current schedule, the first launch of a space station element will take place in November 1995, with permanently occupied capability planned for September 1999. This year, NASA will conduct space station critical design reviews (CDRs). Work package design reviews will take place from February to April 1993, followed by a systems CDR.
Space Station Freedom

Objectives

- Establish preeminent manned space laboratory:
  - Life & material sciences
  - Technology advancement
  - Earth & space observation
- Build infrastructure for man’s evolving space exploration
- Expand our nation’s leadership in civil space programs
- Promote international participation and cooperation
- Develop commercial opportunities and applications
Space Station Freedom: Scope

Architectural Elements
- US Laboratory
- European Laboratory
- Japanese Laboratory & Exposed Facility
- Habitat Module
- Resource Nodes
- Centrifuge Node
- Pre-Integrated Truss
- Logistics Carriers

Distributed Systems
- Electric Power
- Thermal Control
- Data Management
- Guidance, Navigation & Control
- Communication & Tracking
- EVA Support Equipment
- Environmental Control
- Fluids Management
- Propulsion

Ground System

Facilities
- Space Station Control Center
- Payload Operations Integration Center
- Space Station Processing Facility
- Space Station Training Facility
- Payload Training Complex
- Engineering Support Centers

Adjuncts
- Test Checkout and Monitoring System
- Mission Planning System
- Trajectory, Command, Analysis and Timeline System

Key Elements

- ESA Attached Pressurized Module (APM)
- Assured Crew Return Vehicle (ACRV)
- Airlock
- JEM Logistics Carrier
- JEM Exposed Facility
- Centrifuge Node
- Node 1
- Node 2
- Japanese Experimental Module (JEM)
- U.S. Hab Module
- Pressurized Logistics Module (MELPM)
- PMC Module Cluster
Research Objectives Overview

Design Drivers

<table>
<thead>
<tr>
<th>Life Sciences</th>
<th>Material Sciences</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐ Space Biology</td>
<td>☐ Fundamental Mass Transport</td>
</tr>
<tr>
<td>☐ Space Medicine</td>
<td>☐ Inorganic Materials</td>
</tr>
<tr>
<td>☐ Exobiology and Biospherics</td>
<td>☐ Organic Materials</td>
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Inherent Capabilities

<table>
<thead>
<tr>
<th>Earth Sciences</th>
<th>Astronomical Sciences</th>
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<tbody>
<tr>
<td>☐ Global Hydrology</td>
<td>☐ Plasma Physics</td>
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<tr>
<td>☐ Climatology</td>
<td>☐ Solar Physics</td>
</tr>
<tr>
<td>☐ Geophysics</td>
<td>☐ Astrometric Observations</td>
</tr>
</tbody>
</table>

MTC Capability

- 18.75 kW power
- 11 kW to users
- Pressurized volume
  - US Lab - 12 racks
  - Node - 4 racks
- Man-tended operations
- SSRMS control
- High and low data rate communications
- Orbiter berthing with pressurized crew transfer
**PMC Capability**

- 56 25 kW power
- 30 kW to users
- Pressurized volume
  - US Lab
  - ESA APM
  - NASDA JEM
  - US HDP
  - 2 Nodes
- Continuous manned presence
- 4 person crew
- Redundant orbiter berthing locations
- Full MSC capability
- Crew return capability
- Centrifuge

---

**Payload Resources Overview**

**Pressurized Volume:**
- 15 Payload Racks at MTC
- 46 Payload Racks at PMC

**Attached Payload Accommodations:**
- 2 sites at MTC
- 4 sites at PMC

**Launch Capacity:**
- 8 Utilization Flights deliver 64 Payload Racks and 80,000 lbs
- Mission Build flights provide accommodations for an additional 25 Payload Racks

**Power:**
- 10 kW with 1 Photovoltaic Array
- 15 kW with 2 Photovoltaic Arrays
- 20 kW with 3 Photovoltaic Arrays

**Crew-Time:**
- 4 Payload Crew per 16-Day Utilization Flight
- Payload Crew Planned at PMC

**Downlink:**
- 50 Megabits / Second at MTC
Attached Payload Accommodations

Four Payload Accommodation Sites with Resource Ports

- Zenith, nadir, ram, and wake viewing
  - Nadir sites support equatorial and Earth limb remote sensing
- 120 vdc, 3.0 kW, at each site
- 1000 - 3000 cubic feet clearance envelope
- 400 - 700 kbps data downlink, scarred for growth to 10 Mbps

Payload Resource Allocations

- Establishes Top-Level Allocation of both Resources and Accommodations Among the Four Partners
- Applicable to "Utilization" Resources Only
  (i.e., does not apply to "housekeeping" resources for respective station elements)

<table>
<thead>
<tr>
<th></th>
<th>NASA U.S.</th>
<th>MOSST Canada</th>
<th>ESA Europe</th>
<th>STA Japan</th>
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</thead>
<tbody>
<tr>
<td>1. Utilization Resources</td>
<td>71.4%</td>
<td>3.0%</td>
<td>12.8%</td>
<td>12.6%</td>
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<tr>
<td>2. User Accommodations</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>a. NASA Lab Module</td>
<td>97%</td>
<td>3%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. NASA Attached Payload Accommodations</td>
<td>97%</td>
<td>3%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. ESA Attached Pressurized Module (APM)</td>
<td>46%</td>
<td>3%</td>
<td>51%</td>
<td></td>
</tr>
<tr>
<td>d. Japanese Experiment Module (Exposed Facility)</td>
<td>46%</td>
<td>3%</td>
<td>51%</td>
<td></td>
</tr>
<tr>
<td>d. Japanese Experiment Module (Exposed Logistics Module)</td>
<td>46%</td>
<td>3%</td>
<td>51%</td>
<td></td>
</tr>
</tbody>
</table>
**Greater Utilization Capabilities**

- **Includes**
  - User Power
  - User Racks
  - Crew Time
  - Payload Operations

**Benefits of the Space Environment**

- Absence of buoyancy-driven convection
- Absence of sedimentation
- Absence of hydrostatic pressure
- Presence of ultra-high vacuum

**Research Objective:**

Technology advances through improved control of process variables, such as temperature, composition and flows
Absence of Buoyancy-Driven Convection

- Microgravity conditions eliminate convective flows in molten metals, liquids and gases due to density differences.

- Diffusion becomes the primary mechanism for thermal and mass transport.

- Diffusion processes can be accurately predicted and controlled.

- Important applications:
  - Dopant distribution in crystal growth
  - Identification of mechanisms for segregation in alloys
  - Prevention of mixing in purification processes
  - Understanding of fluid dynamic effects in systems undergoing phase changes

Absence of Sedimentation

- In Earth gravity it is possible to maintain a suspension of particles in a fluid if the particles are < 1 m.

- Microgravity conditions permit suspensions involving particles >1 m.

- Important applications:
  - Chemical refinement of glasses
  - Preparation of unique foams (ultra-light structures)
  - Control of flocculation processes
  - Preparation of immiscible alloys
  - Improved polymerization processes
Absence of Hydrostatic Pressure

- Microgravity conditions eliminate the tendency for a liquid or solid to deform under its own weight.
- Important applications:
  - Modification of critical points in solid, liquid, and gas phase transitions
  - Ability to form stable floating zones large in length and diameter (an important crystal growth technique)
  - Formation of thin oxide skins to produce intricate casting molds
  - Growth of large complex macromolecules, such as proteins, for structural analysis and drug design

Presence of Ultra-High Vacuum

- Vacuum chambers on earth approach $10^{-13}$ torr, however, pumping capacity is limited unless large cryogenic panels are used (incompatible with high heat loads in molten systems)
- Space vacuum approaches $10^{-18}$ torr with virtually infinite pumping capability
- Important applications:
  - High temperature materials purification
  - Vapor deposition on ultraclean surfaces
  - Preparation of thin single crystal films
  - Use of container-less techniques to avoid container contamination
Near Term Milestones

September 1992  Canadian Mobile Servicing Center (MSC) Phase 1 CDR
2nd Qtr 1993  Man Tended Capability (MTC) Critical Design Review (CDR)
4th Qtr 1993  Permanently Manned Capability (PMC) CDR
October 1993  Canadian MSC Phase 2 CDR
November 1994  European Space Agency (ESA) Attached Pressurized Module (APM) CDR
December 1994  Japanese Experimental Module (JEM) CDR
4th Qtr 1995  First Element Launch (FEL)

Summary

- Space Station Freedom satisfies our manned space research objectives
  - Life & material sciences
  - Technology advancement
  - Earth & space observation
- Space Station Freedom represents mankind's evolving exploration in space
- Space Station Freedom demonstrates our nation's leadership in international space programs
- Space Station Freedom can serve as a model for all future multi-national space endeavors
Great Nations Dare To Explore

It's Time For America To Take Its Place On The Final Frontier
OPPORTUNITIES FOR RESEARCH ON SPACE STATION FREEDOM

Presented by Dr. Robert Phillips
NASA Office of Space Systems Development
NASA Headquarters

ABSTRACT

NASA has allocated research accommodations on Freedom (equipment, utilities, etc.) to the program offices that sponsor space-based research and development as follows: Space Science and Applications (OSSA) — 52 percent, Commercial Programs (OCP) — 28 percent, Aeronautics and Space Technology (OAST) — 12 percent, and Space Flight (OSF) — 8 percent.

Most of OSSA’s allocation will be used for microgravity and life science experiments; although OSSA’s space physics, astrophysics, earth science and applications, and solar system exploration divisions also will use some of this allocation.

Other Federal agencies have expressed an interest in using Space Station Freedom. They include the National Institutes of Health (NIH), U.S. Geological Survey, National Science Foundation, National Oceanic and Atmospheric Administration, and U.S. Departments of Agriculture and Energy.

Payload interfaces with space station lab support equipment must be simple, and experiment packages must be highly contained. Freedom’s research facilities will feature International Standard Payload Racks (ISPRs), experiment racks that are about twice the size of a Spacelab rack. ESA’s Columbus lab will feature 20 racks, the U.S. lab will have 12 racks, and the Japanese lab will have 10. Thus, Freedom will have a total of 42 racks versus 8 for Spacelab.

NASA is considering outfitting some rack space to accommodate small, self-contained payloads similar to the Get-Away-Special canisters and middeck-locker experiment packages flown on Space Shuttle missions. Crew time allotted to experiments on Freedom at permanently occupied capability will average 25 minutes per rack per day, compared to six hours per rack per day on Spacelab missions. Hence, telescience — the remote operation of space-based experiments by researchers on the ground — will play a very important role in space station research.

Plans for supporting life sciences research on Freedom focus on the two basic goals of NASA’s space life sciences program: to ensure the health, safety, and productivity of humans in space and to acquire fundamental knowledge of biological processes.

Space-based research has already shown that people and plants respond the same way to the microgravity environment: they lose structure. However, the mechanisms by which they respond are different, and researchers do not yet know much about these mechanisms. Life science research accommodations on Freedom will include facilities for experiments designed to address this and other questions, in fields such as gravitational biology, space physiology, and biomedical monitoring and countermeasures research.
OPPORTUNITIES FOR RESEARCH ON SPACE STATION FREEDOM

ROBERT W. PHILLIPS
CHIEF SCIENTIST
SPACE STATION FREEDOM

SPACE STATION FREEDOM WILL BE:

• A WORLD CLASS MICROGRAVITY LABORATORY

• AN INTERNATIONAL FACILITY DESIGNED TO ADVANCE SCIENCE AND TECHNOLOGY IN THE SPACE ENVIRONMENT

• A TEST BED FOR DEVELOPING THE EXPERIENCE AND TECHNOLOGIES TO EXPLORE THE MOON AND MARS
### USER ORGANIZATION SUBALLOCATIONS

<table>
<thead>
<tr>
<th>ORGANIZATION</th>
<th>SUB ALLOCATION OF RESOURCES</th>
</tr>
</thead>
<tbody>
<tr>
<td>OFFICE OF SPACE SCIENCE AND APPLICATIONS (OSSA)</td>
<td>52%</td>
</tr>
<tr>
<td>OFFICE OF COMMERCIAL PROGRAMS (OCP)</td>
<td>28%</td>
</tr>
<tr>
<td>OFFICE OF AERONAUTICS AND SPACE TECHNOLOGY (OAST)</td>
<td>12%</td>
</tr>
<tr>
<td>OFFICE OF SPACE FLIGHT (OSF)</td>
<td>8%</td>
</tr>
</tbody>
</table>

### OFFICE OF SPACE SCIENCE AND APPLICATIONS

- DIVISION OF LIFE SCIENCES
- DIVISION OF MICROGRAVITY SCIENCES
- DIVISION OF EARTH SCIENCE AND APPLICATIONS
- DIVISION OF SPACE PHYSICS
- DIVISION OF ASTROPHYSICS
- DIVISION OF SOLAR SYSTEM EXPLORATION
SSF WILL HOUSE
DEDICATED CORE
RESEARCH FACILITIES
IN THE PRESSURIZED
VOLUME
• USER-PROVIDED CORE FACILITIES CAN BE SUPPLEMENTED BY EXPERIMENT-UNIQUE EQUIPMENT AND GENERAL LABORATORY SUPPORT EQUIPMENT.

• SSF WILL PROVIDE THE BASIC UTILITIES NEEDED TO SUPPORT EXPERIMENT OPERATION (DATA MANAGEMENT, POWER, COOLING, ETC.).

Space Station Freedom Module Cluster

Assured Crew Return Vehicle

US Hab

Node 1

ESA Attached Pressurized Module

JEM Experiment Logistics Module PS

US Lab

Airlock

Node 2

JEM Pressurized Module

Velocity
The large payload complement on Space Station Freedom will make crew time a valuable resource.

Crew hours per payload rack comparison with Spacelab:

- Spacelab typically offers about 6 hours per (double) rack per day;

- At PMC, Space Station will offer about 25 minutes per rack per day.

(One Space Station rack is equivalent to a Spacelab double rack)

Reduced crew time available for each rack mandates an increase in the use of automation and/or telescience in payload design.
DEDICATED SMALL PAYLOAD ACCOMMODATIONS RACK CONCEPT

Existing Container Hardware:

- EAC
- Middeck Locker
- Slide-in Drawer

Integrated Small Payload System

LIFE SCIENCES

MICROGRAVITY SCIENCES

ATTACHED PAYLOADS
LIFE SCIENCES ON SPACE STATION FREEDOM

WILL PROVIDE THE OPPORTUNITY TO STUDY MULTIGENERATIONAL EFFECTS OF SPACE EXPOSURE ON PLANTS AND ANIMALS

MICROGRAVITY SCIENCE FACILITIES

- ADVANCED PROTEIN CRYSTAL GROWTH
- SPACE STATION FURNACE
- COMBUSTION
- FLUID PHYSICS DYNAMICS
- CONTAINERLESS PROCESSING
- BIOTECHNOLOGY
ATTACHED PAYLOADS WILL PROVIDE THE OPPORTUNITY:

- TO STUDY THE SPACE ENVIRONMENT
- TO OBSERVE THE EARTH'S TROPICAL REGIONS
- TO OBSERVE OUTWARD

Japanese Experiment Module - Exposed Facility (JEM - EF)

Flight Direction

3.1 m
4.9 m
1.2 m

Equipment Exchange Units (EEUs) Grapple Fixture Orbit Replaceable Units

Grapple Fixture - allows handling of JEM - EF by RMS

EEU - Attachment point for JEM - EF payloads

ORUs - equipment such as DC to DC Converter Units which can be replaced while on-orbit

External Payload positions are 1 - 8, 12, 13
SPACE STATION FREEDOM REPRESENTS THE FIRST OPPORTUNITY TO DEVELOP A PROGRAM TO UNDERSTAND AND EXPLAIN MICROGRAVITY EFFECTS AND THE SPACE ENVIRONMENT.

IT IS, HOWEVER, A BEGINNING, NOT AN END.

WE URGE YOU TO JOIN IN THIS ADVENTURE!
HOW TO GET ON BOARD SPACE STATION FREEDOM

Presented by Dr. John-David Bartoe
User Integration Division
Spacelab/Space Station Utilization Program
NASA Headquarters

ABSTRACT

Space Station Freedom will accommodate researchers with interests in science, technology and commercial applications. NASA sponsors will be responsible for selecting the U.S. researchers for Space Station Freedom. The four NASA sponsors are: Office of Space Science and Applications (OSSA), Office of Aeronautics and Space Technology (OAST), Office of Commercial Programs (OCP), and the Office of Space Flight (OSF). The areas of research responsibility for each sponsor are presented. The researcher solicitation vehicles used by OSSA and OAST and the methodology for researchers seeking sponsorship from OCP and OSF as well as the pricing policy are discussed.

Descriptions of flight planning, payload integration and operations functions are presented. Three categories of payloads and their respective payload integration times are discussed. Researchers are advised to contact a NASA sponsor and a source which lists the points of contact for the NASA sponsors is noted.
HOW TO GET ON BOARD
SPACE STATION FREEDOM

Presentation to the
Space Station Freedom
Utilization Conference
Huntsville, AL
August 3-6, 1992

Dr. John-David Bartoe
Director
User Integration Division
Spacelab/Space Station
Utilization Program

SPACE STATION FREEDOM RESEARCH
GETTING A SPONSOR

- Space Station Freedom research capabilities are shared by Canada, ESA, Japan and NASA

- Researchers who wish to use NASA's share enter the program through a NASA sponsor

- NASA sponsoring organizations are the primary agents for initiating, selecting and implementing research

- Each NASA sponsoring organization is allocated a block of Freedom's accommodations and resources
The sponsor develops research plans:

- Within the sponsor's mandate
- Responsive to its research community

To achieve their goals, sponsors:

- Perform outreach to their constituencies
- Develop mechanisms to select payloads for flight
- Advocate for their research needs within the agency
- Manage their research program, including payload development, integration and operations
- Fund research, as appropriate to their mandate

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**NASA SPONSORING ORGANIZATIONS**

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**RESEARCHERS**

Science and Applications Researchers
Technology Development Researchers
Commercial Cooperative Researchers
Commercial Reimbursable Researchers

NASA Office of Space Science and Applications (OSSA)
NASA Office of Aeronautics and Space Technology (OAST)
NASA Office of Commercial Programs (OCP)
NASA Office of Space Flight (OSF)
• Sponsored by Office of Space Science and Applications (OSSA)

• Includes research by other government agencies, such as NIH, NSF, etc.

• Life Sciences Research
  -- Ensure the health, safety and productivity of humans in space
    - Monitor crew health
    - Develop countermeasures to adverse effects of prolonged exposure to low gravity
  -- Acquire fundamental scientific knowledge in space life sciences
    - Study the effects of gravity on living systems
Microgravity Science and Applications

Materials Science
- Electronic and photonic materials
- Metals and alloys
- Glasses and ceramics

Fundamental sciences, including the study of
- Fluid dynamics and transport phenomena
- Combustion science
- Gravitational physics

Biotechnology experiments
- Macromolecular crystal growth
- Cell and molecular science
SCIENCE AND APPLICATIONS RESEARCHERS

- OSSA issues Announcements of Opportunity (AOs) and NASA Research Announcements (NRAs)
- AOs solicit proposals which involve major hardware procurements
- NRAs solicit proposals for utilizing existing hardware or involving minor hardware development
- AOs and NRAs solicit proposals for ground-based and research in space (e.g., Spacelab and Space Station)
- Four NRAs for Microgravity Science and Applications have already been released. Future NRAs will be released on a regular schedule.
- First AO/NRA for Life Sciences to be released approximately 2 years before First Element Launch (first AO/NRA expected 1994)

TECHNOLOGY RESEARCHERS

- Sponsored by Office of Aeronautics and Space Technology (OAST)
- OAST is responsible for the development of enabling and enhancing technologies for the Nation’s future space missions
- Includes technology experiments by other government agencies, such as DOD R&D
- Flight experiment program objective is to:
  - Validate technology in space
  - Obtain data which are unobtainable on the ground
- OAST emphasizes small and inexpensive experiments
- OAST solicits proposals through the periodic release of AOs
- Next OAST AO expected to be released within next few weeks
Technology Development Areas:
-- Structural Dynamics
-- Robotics
-- Sensors and Information Systems
-- Life Support Systems
-- Materials and Environmental Effects
-- Fluid Transfer and Storage
-- Thermal Management
-- Power Systems
-- Propulsion
• Sponsored by the Office of Commercial Programs (OCP)

• Objective of commercial cooperative research is for NASA to provide industry assistance, services, and access to facilities to encourage the commercial use of space

• Commercial cooperative researchers are those who are partially funded by NASA

• Commercial cooperative researchers generally provide some type of compensation or *quid pro quo*

• Agreements between OCP and researcher dependent upon degree of risk researcher is willing to take
COMMERCIAL COOPERATIVE RESEARCHERS

- Centers for the Commercial Development of Space (CCDSs) are the primary commercial cooperative user entry points.

- Seventeen CCDSs focus on the following disciplines:
  - Automation and robotics
  - Remote sensing
  - Biotechnology
  - Materials processing in space
  - Space power
  - Space structures
  - Communications

COMMERCIAL REIMBURSABLE RESEARCHERS

- Sponsored by the Office of Space Flight (OSF)

- Researcher who pays the established price for use of Space Station (including pro rata Space Shuttle transportation to and from Freedom)

- Submits request for flight and earnest money to OSF

- Negotiates agreement with OSF

- The point of contact is NASA OSF Policy and Plans Division
COMMERCIAL REIMBURSABLE RESEARCH

REIMBURSABLE PRICING POLICY

- Cost to reimbursable researcher will be dependent upon two factors:
  -- Pricing policy
  -- Cost basis

- Pricing policy defines the algorithm for charging for use of the Station:
  -- Accommodations
  -- Resources
  -- Standard services

- Cost basis defines the dollar cost for each "unit of use"

- Pricing policy and cost basis are under agency development and review

- Pricing policy will be set by the Administrator and reviewed by Congress

- Public review and comment period required
  -- Will be announced in Federal Register
  -- Current plan for release early 1993
• Reimbursable pricing policy concept currently under development

• Shuttle and Spacelab policies used as a base

• Two standard service packages
  -- Round-trip transportation and integration
  -- On-orbit operations

• Round-trip transportation and integration price based on:
  -- Weight
  -- Volume
  -- Length

• On-orbit operations price based on:
  -- Space
  -- Energy
  -- Crew time
  -- Length of stay

• Optional services available

• Final pricing structure (i.e., policy) will be determined after a thorough management review

• Cost basis to be defined based upon degree of cost recovery
The Space Station Freedom program has developed a planning process that identifies when a payload flies.

Flight planning provides the researcher with a commitment to fly.

The process uses a 5 year planning horizon.

Researchers are not directly involved this far in advance unless the payload is very complex.
WHAT IS PAYLOAD INTEGRATION?

- Payload integration is the process used to assemble a complement of payloads for flight on Space Station Freedom and return to Earth.

- The payload integration process can be characterized by three individual integration functions:
  
  1. Analytical integration
  2. Physical integration
  3. Operational Integration
The Payload Analytical Integration function includes:

- Technical assistance and support to the user
- Assurance that user and program requirements are met
- Assurance of compatible interfaces
- Verification of the safety of the payload and payload complement for launch and on-orbit operation
The Payload Physical Integration function includes:

1. Development of procedures for physical integration and testing
2. Functional testing of the payload (optional service)
3. Integration of payloads into carriers
4. Performance of final pre-launch interface verification testing for the integrated payload carrier
5. Support to on-orbit payload integration and deintegration
6. Performance of post-landing physical deintegration

The Payload Operations Integration function includes:

1. Operations planning for payloads
   -- Assurance of operational compatibility of payload complements
   -- Generation of payload operations agreements
   -- Development and management of payload operations timelines
2. Training and simulation exercises for flight and ground crew
PAYLOAD OPERATIONS

- The Payload Operations functions:
  -- Provide interface to crew
  -- Build and uplink commands
  -- Build and uplink crew procedures
  -- Payload replanning
    - Research support
    - Hardware malfunctions
    - Other anomalies
    - Update orbital conditions
    - Update resource consumption
  -- Data Management
    - Process and provide payload data
    - Provide video/data playback
  -- Support payload performance assessments
The payload integration process is currently under study to better reflect the changing requirements of the payload community and support more flexibility within the process.

-- The payload trend is moving toward the smaller, simpler payloads.

-- The aim is to define a process that will accommodate a large number of payloads with a wide range of requirements while minimizing cost and allowing quick integration.
PAYLOAD

Sub-Rack Payloads:
-- Existing flight-qualified containers
-- Simple interfaces and operations
-- Standard integration agreements

Rack Payloads:
-- Unique user-provided and integrated
-- International Standard Payload Rack interfaces
-- Moderately complex operations
-- Standard integration agreements

Multi-Rack Payloads:
-- Unique user-provided racks
-- Integrated on orbit
-- Non-standard interfaces
-- Complex operations
-- Non-standard agreements

A SPACE STATION FREEDOM RACK
INTEGRATION TIME VS. COMPLEXITY

- 80% of Proposed Payloads
- 60% of Proposed Payloads

Physical Integration Complexity

Payload Integration Process Duration

12 mos 24 mos

SUMMARY

- Those who wish to perform research on Freedom may contact one of the four NASA sponsoring organizations

- The payload integration process is being streamlined to better accommodate researchers

- The points of contact for each of the NASA user sponsoring organizations are identified in article available at the NASA Headquarters booth:
  "How to Get On Board Space Station Freedom"

- Contact NASA Headquarters if you have any questions:

  Dr. John-David Bartoe, Director, User Integration Division
  Barry Epstein, User Development Program Manager
  (202) 453-1181
HOW TO GET ON BOARD
SPACE STATION FREEDOM

Points of Contact

Science and Applications Opportunities
Dr. Roger Crouch
Microgravity Science & Applications Division
Office of Space Science & Applications
NASA Headquarters/Code SN
Washington, DC 20546

Dr. J. Richard Keefe
Life Sciences Division
Office of Space Science & Applications
NASA Headquarters/Code SB
Washington, DC 20546

Technology Development Opportunities
Dr. Judith H. Ambrus
Space Experiments Office
Office of Aeronautics and Space Technology
NASA Headquarters/Code RSX
Washington, DC 20546

Commercial Cooperative
James Fountain
Office of Commercial Programs
PS05
George C. Marshall Space Flight Center
Huntsville, AL 35812

Commercial Reimbursable Opportunities
Office Space Flight
NASA Headquarters/Code MB
Washington, DC 20546

For General Information about Space Station
Freedom Research Capabilities and
Opportunities:
Dr. John-David Bartoe, Director
User Integration Division
Spacelab/Space Station Utilization Program
NASA Headquarters/Code MG
Washington, DC 20546
(202) 453-1181
NASA'S COMMERCIAL RESEARCH PLANS AND OPPORTUNITIES

Presented by Ray J. Arnold
Office of Commercial Programs
NASA Headquarters

ABSTRACT

One of the primary goals of the National Aeronautics and Space Administration’s (NASA) commercial space development plan is to encourage the development of space-based products and markets, along with the infrastructure and transportation that will support those products and markets. A three phased program has been instituted to carry out this program. The first phase utilizes government grants through the Centers for the Commercial Development of Space (CCDS) for space-related, industry driven research; the development of a technology data base; and the development of commercial space transportation and infrastructure. The second phase includes the development of these technologies by industry for new commercial markets, and features unique industry/government collaborations such as Joint Endeavor Agreements. The final phase will feature technical applications actually brought to the marketplace. The government’s role will be to support industry required infrastructure to encourage start-up markets and industries through follow-on development agreements such as the Space Systems Development Agreement.

The Office of Commercial Programs has an aggressive flight program underway on the Space Shuttle, suborbital rockets, orbital expendable launch vehicles, and the Commercial Middeck Accommodation Module with SPACEHAB Inc.

The Office of Commercial Program’s has been allocated 35% of the U.S. share of the Space Station Freedom resources for 1997 utilization. A utilization plan has been developed with the Centers for the Commercial Development of Space and has identified eleven materials processing and biotechnology payloads occupying 5 double racks in the pressurized module as well as two payloads external to the module in materials exposure and environment monitoring. The Office of Commercial Programs will rely on the Space Station Freedom to provide the long duration laboratory component for space-based commercial research.
Opportunities for Commercial Research in Space

- Objective
  - Conduct industry driven, space based, high technology, applied research and to allow U.S. industry to develop new or improved commercial products

- Goal
  - Increase the private sector participation and investment while diminishing the associated up-front financial and technical risks
Commercial Research Plans and Opportunities

• The Office of Commercial Programs relies on the Space Station Freedom to provide the long duration laboratory component for space-based commercial research.

• The Office of Commercial Programs is creating all of the ingredients in the recipe for the success of U.S. private sector leadership in space by providing:
  - Opportunities for focused research
    • Centers for the Commercial Development of Space
  - Basic experimental apparatus
    • Material science furnaces
    • Commercial refrigerator/incubator modules
    • Thermal enclosure systems
  - Precursor experimental space flights
    • Space Shuttle
    • SPACEHAB
    • COMmercial Experiment Transporter
    • Wakeshield Facility

Mechanisms for Commercial Research
Relationships with Industry are in Place

• Affiliation with the Centers for the Commercial Development of Space

• Collaborative agreements with NASA
  (Joint Endeavor Agreement, Technical Exchange Agreements)

• Reimbursable flight agreements
  (Space Systems Development Agreement)
The Office of Commercial Programs encourages and supports U.S. private sector leadership in space-related commerce

Centers for the Commercial Development of Space (CCDS) Program

- Non-profit consortia of industry, academia and government
- Conduct industry driven space-based, high-technology research and development
- Research areas include materials processing, biotechnology, remote sensing, automation and robotics, space power, space propulsion, space structures and communications
- Created in 1985 to maximize U.S. industry leadership in commercial space-related activities
- Designed to increase private sector participation and investment in the commercial development of space
- Provide a way for U.S. companies to pool resources and expertise while diminishing the associated costs and risks
- To participate in the CCDS program, a company should contact the appropriate CCDS Center Director
Centers for Commercial Development of Space (CCDS)

Current CCDS Commercial Technologies

Auburn
- Solar Furnace Satellite
- Crystal Growth of Electronic Materials
- Computational Modeling of Casting Processes

Battelle
- Solution Crystal Growth
- Polymer Composites
- Float Zone Crystal Growth - CdTe
- Zeolite Crystal Growth
- Doped Nonlinear Optic Substrates
- Investigations Into Polymer Membranes

Boeing
- Plant Growth Apparatus
- Blood Rheology Experiment
- Generic Bioprocessing Module
- Autonomous Biomedical Test Apparatus

Case Western Reserve University
- Materials Exposure - Basic, Advanced, & Applied

Clarkson
- Zeolite Crystal Growth
- Low-Temp Solidification
- Liquid Encapsulated Melt Zone
- Directional Solidification - CdTe
- Chemical Vapor Transport - CdTe
- Commercial Solution Growth Facility

CSTAR
- Cryogenic Fluid Management
- Electric, Chemical Propulsion
- Industrial Laser System Applications

Florida Atlantic University
- Transmission Techniques

Ohio State University
- Remote Sensing & Mapping

Penn State University
- Biomedical
- Telemedicine
- Bioprocessing
- Bone Densitometry
- Physiological Systems Experiment
- Light Stimulator & Photon Detector
- Commercial Electrophoresis System

SpARCS
- Autonomous Rendezvous & Docking
- Automated Microgravity Materials Processing

SRSRC
- Remote Sensing & Applications

SVEC
- Chemical, Molecular Beam Epitaxy Growth

Texas A&M
- Micro Heat Pipe Evaluation
- Frozen Startup of Heat Pipe
- Microwave Power Transmission

University of Alabama-Birmingham
- Protein Crystal Growth

University of Alabama-Huntsville
- Polymer Foam
- Atomic Oxygen
- Electrodeposition
- 3-D Accelerometer
- Immiscible Polymers
- Nuclear Track Detectors
- Space Experiment Facility
- Non-Linear Optical Materials
- Sintered & Alloyed Materials
- High-Temp Superconductors
- Materials Dispersion Apparatus

University of Maryland
- Hybrid Networks

WCSAR
- Astroculture™
- Bioregenerative Water System
## Active Commercial Agreements

<table>
<thead>
<tr>
<th>Company</th>
<th>Venture</th>
<th>Status</th>
<th>Requirement</th>
<th>Flights Completed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Joint Endeavor Agreements</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Instrumentation Technology Associates</td>
<td>Standardized Experiments Carrier</td>
<td>Hardware under development, first flight TBD</td>
<td>2 flights (cross-bay carrier)</td>
<td>0</td>
</tr>
<tr>
<td>3M (10 years)</td>
<td>Research in organic and polymer chemistry</td>
<td>First payload (payload STS-34 Oct 1989)</td>
<td>62 flights (20 middeck; 42 cargo bay)</td>
<td>3</td>
</tr>
<tr>
<td>Boeing Aerospace Company (BAC)</td>
<td>Crystal growth experiments on the shuttle</td>
<td>Hardware under development, first flight planned for STS-52 (Sept 1992)</td>
<td>3-5 flights (Mor)</td>
<td>0</td>
</tr>
<tr>
<td><strong>Technical Exchange Agreements</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Autometric, Inc.</td>
<td>High resolution handheld remote sensors</td>
<td>Signed 4/2/91</td>
<td>Access to NASA Imagery from the Electronic Still Camera developed by JSC</td>
<td>2</td>
</tr>
<tr>
<td><strong>Other Cooperative Agreements</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>University of Alabama - Huntsville Instrumentation Technology Associates</td>
<td>Materials processing using a minimal dispersion apparatus</td>
<td>First flight planned for STS-52 (Sept. 92)</td>
<td>5 flights 1 locker</td>
<td>0</td>
</tr>
</tbody>
</table>

---

**Flight Planning**
Commercial Transportation Modes

Commercial development of space programs require a variety of transportation modes, and an assured, frequent, cost-effective means to access space.

 Various shuttle experiments (continuing)

Parabolic aircraft flights (continuing)

Suborbital rockets

- 30-35 KC-135 payload-flights per year

Flights of U.S. Commercial Payloads

<table>
<thead>
<tr>
<th>Payload Name</th>
<th>No. of Flights</th>
<th>Missions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Astroculture</td>
<td>2</td>
<td>STS 50</td>
</tr>
<tr>
<td>Automated Generic Bioprocessing Apparatus</td>
<td>2</td>
<td>Consort 3.4</td>
</tr>
<tr>
<td>Biomodule</td>
<td>2</td>
<td>Consort 3.4</td>
</tr>
<tr>
<td>Bioactive Instrumentation Materials Dispersion App.</td>
<td>2</td>
<td>STS 37.43</td>
</tr>
<tr>
<td>Continuous Flow Electrophoresis (I, II, &amp; III)</td>
<td>2</td>
<td>STS 4.6, 7, 8, 12, 16, 23</td>
</tr>
<tr>
<td>Deriving of Immobile Polymers Mixt.</td>
<td>2</td>
<td>Consort 3.4</td>
</tr>
<tr>
<td>Diffusive Mixing of Organic Solutions</td>
<td>2</td>
<td>STS 14.15</td>
</tr>
<tr>
<td>Directed Polymerization Apparatus (USML-1 GBX exp.)</td>
<td>1</td>
<td>STS 50</td>
</tr>
<tr>
<td>Ejector Modified Epoxy Resin Heaters</td>
<td>2</td>
<td>Consort 3.4</td>
</tr>
<tr>
<td>Electrodeposition Cells</td>
<td>4</td>
<td>Consort 3.4, STS 40 (GAS 105)</td>
</tr>
<tr>
<td>Equipment for Controlled Liquid Phase Sintering</td>
<td>1</td>
<td>Consort 3.4</td>
</tr>
<tr>
<td>Fluid Experiment Apparatus</td>
<td>2</td>
<td>STS 20.32</td>
</tr>
<tr>
<td>Foam Formation Device</td>
<td>2</td>
<td>Consort 3.4</td>
</tr>
<tr>
<td>Galation of SOLS: Applied Microgravity Research</td>
<td>1</td>
<td>STS 42</td>
</tr>
<tr>
<td>Generic Bioprocessing Apparatus</td>
<td>1</td>
<td>STS 50</td>
</tr>
<tr>
<td>Protein Crystal Growth (Hand-Held, VOA, POF, CRM)</td>
<td>1*</td>
<td>STS 16, 19, 21, 23, 24, 26, 29, 32, 33, 37, 53, 63, 73, 83</td>
</tr>
<tr>
<td>Investigations into Polymer Membrane Processes</td>
<td>2</td>
<td>Consort 3.4</td>
</tr>
<tr>
<td>Investigations into Polymer Membrane Processing</td>
<td>7</td>
<td>STS 41, 43, 48, 42, 45, 50</td>
</tr>
<tr>
<td>Materials Dispersion Apparatus</td>
<td>3</td>
<td>Consort 3.4</td>
</tr>
<tr>
<td>Metal Sintering Furnace</td>
<td>1</td>
<td>Consort 3.4</td>
</tr>
<tr>
<td>Non-Linear Optical Crystal Growth (DAN)-UMVERM</td>
<td>1</td>
<td>STS 40 (GAS 105)</td>
</tr>
<tr>
<td>Non-Linear Optical Crystal Growth (DAN)-UMVBM</td>
<td>1</td>
<td>STS 40 (GAS 105)</td>
</tr>
<tr>
<td>Physical Vapor Transport of Organic Solids</td>
<td>2</td>
<td>STS 20.26</td>
</tr>
<tr>
<td>Physiological Systems Experiments</td>
<td>1</td>
<td>STS 41</td>
</tr>
<tr>
<td>Plasma Particle Generation</td>
<td>1</td>
<td>Consort 3.4</td>
</tr>
<tr>
<td>Polymer Coating Experiment</td>
<td>1</td>
<td>Consort 3.4</td>
</tr>
<tr>
<td>Polymer Morphology</td>
<td>1</td>
<td>STS 34</td>
</tr>
<tr>
<td>Polymer Thin Films</td>
<td>2</td>
<td>Consort 3.4, STS 40 (GAS 105)</td>
</tr>
<tr>
<td>Separation of Aqueous Phases</td>
<td>1</td>
<td>STS 40 (GAS 105)</td>
</tr>
<tr>
<td>Space Formed Structural Beam (Foam Foundation Device)</td>
<td>1</td>
<td>Consort 3.4</td>
</tr>
<tr>
<td>1 Yeast Experiment</td>
<td>1</td>
<td>STS 40 (GAS 105)</td>
</tr>
<tr>
<td>Zeolite Crystal Growth</td>
<td>1</td>
<td>STS 50</td>
</tr>
</tbody>
</table>

Total number of payloads flown - 73**
Hardware items - 32

* The Protein Crystal Growth experiments were shared between the OCP and OSSA
**A payload-flight = one flight of one payload. Therefore, one flight with = 3 payload-flights
**Flight Profile**

![Flight Profile Chart]

**Office of Commercial Programs**

**Near Term Flight Projection**

<table>
<thead>
<tr>
<th>Flight</th>
<th>Sponsor</th>
<th>Payload</th>
<th>Launch Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>STS-46</td>
<td>Case Western, UAH/Los Alamos Nat Labs, UAH/Elektro Brown</td>
<td>Limited Duration Candidate Materials Exposure (3)<em>, CONCAP-III</em> (Complex Autonomous Payload), CONCAP-III* (Complex Autonomous Payload)</td>
<td>Jul 1992</td>
</tr>
<tr>
<td>STS-47</td>
<td>UAB</td>
<td>Protein Crystal Growth**</td>
<td>Sept 1992</td>
</tr>
<tr>
<td>STS-54</td>
<td>Bioserve</td>
<td>Generic Bioclimatological Apparatus*</td>
<td>Dec 1992</td>
</tr>
</tbody>
</table>

* Assigned
** OSSA Sponsored Joint Flight Activity

Note: Shuttle flight dates are based on internal manifest planning as of 6/4/92

---

[Office of Commercial Programs] National Aeronautics and Space Administration

CE 8000-1 7/28/92
### Office of Commercial Programs
#### Near Term Flight Projection (continued)

<table>
<thead>
<tr>
<th>Flight</th>
<th>Sponsor</th>
<th>Payload</th>
<th>Launch Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>UAH</td>
<td></td>
<td>Biomodule*</td>
<td></td>
</tr>
<tr>
<td>Penn State</td>
<td>UAB</td>
<td>Protein Crystal Growth*</td>
<td></td>
</tr>
<tr>
<td>ERIM</td>
<td>FAU</td>
<td>Autonomous Rendezvous Docking* Motorola Communications Experiment*</td>
<td></td>
</tr>
<tr>
<td>Texas A&amp;M</td>
<td></td>
<td>Frozen Startup of a Heat Pipe in Microgravity*</td>
<td></td>
</tr>
<tr>
<td>STS-51</td>
<td>Advanced Communications Technology Satellite</td>
<td>Case Western</td>
<td>Mar 1993</td>
</tr>
<tr>
<td>UAB</td>
<td>Limited Duration Candidate Materials Exposure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Batelle/Amoco</td>
<td></td>
<td>Commercial Protein Crystal Growth*</td>
<td></td>
</tr>
<tr>
<td>UAB</td>
<td></td>
<td>Investigations into Polymer Membrane Processing*</td>
<td></td>
</tr>
<tr>
<td>STS-56</td>
<td>UAH/ITA</td>
<td>Commercial ITA Materials Dispersion Experiment</td>
<td>Apr 1993</td>
</tr>
</tbody>
</table>

* * Assigned  
** OSSA Sponsored Joint Flight Activity  
Note: Shuttle flight dates are based on internal manifest planning on 6/4/92.

---

### Office of Commercial Programs
#### Near Term Flight Projection (continued)

<table>
<thead>
<tr>
<th>Flight</th>
<th>Sponsor</th>
<th>Payload</th>
<th>Launch Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>STS-57</td>
<td>Battelle</td>
<td>Spacehab 01</td>
<td>May 1993</td>
</tr>
<tr>
<td>Bioserve</td>
<td></td>
<td>Investigations into Polymer Membrane Processing*</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Solution Crystal Growth*</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Zeolite Crystal Growth*</td>
<td></td>
</tr>
<tr>
<td>Clarkson</td>
<td>Bioserve Pilot Laboratory*</td>
<td>Commercial Generic Bioprocessing Apparatus*</td>
<td></td>
</tr>
<tr>
<td>Penn State Univ</td>
<td>Liquid Encapsulated Melt Zone 1*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UAB</td>
<td>Physiological Systems Experiment*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UAH</td>
<td>Commercial Protein Crystal Growth*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UAH</td>
<td>Equipment for Controlled Liquid Phase Sintering*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wisconsin</td>
<td>Organic Separation*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LaRC</td>
<td>3 Dimensional Microgravity Accelerometer*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>JSC</td>
<td>Astroculture*</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gas Permeable Polymer Material*</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Application Specific Preprogrammed Experimental Culture (plus other Space Life Sciences activities)*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LaRC</td>
<td>Space Acceleration Measurement System*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UAH</td>
<td>CONCAP II</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UAH</td>
<td>CONCAP IV</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* * Assigned  
** OSSA Sponsored Joint Flight Activity  
Note: Shuttle flight dates are based on internal manifest planning on 6/4/92.
Commercial Utilization of Space Station Freedom

Rationale for Commercial Space Station Involvement

- Provides the important long duration laboratory component which will enable commercial technologies to transition to new, space-based markets
- Provides natural evolution from shuttle experience for commercial payloads
- Adequate rack volume and power to support commercial payloads
- Most commercial payloads can operate within Space Station microgravity levels
- Payloads can take advantage of untended periods - free flyer environment
- Allows for commercial infrastructural considerations
Space Station Freedom Resource Allocations

<table>
<thead>
<tr>
<th></th>
<th>NASA U.S.A.</th>
<th>MOSST Canada</th>
<th>ESA Europe</th>
<th>STA Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utilization Resources</td>
<td>71.4%</td>
<td>3%</td>
<td>12.8%</td>
<td>12.8%</td>
</tr>
</tbody>
</table>

1997 OCP SSF Resources

- Pressurized Up Mass: 4,352 kg
- Pressurized Down Mass: 3,784 kg
- Unpressurized Up Mass: 4,209 kg
- Unpressurized Down Mass: 7,073 kg
- Volume Up: 9.5 DRE
- Volume Down: 7.1 DRE
- Power: 3 kW
- Downlink: 10,472 kb/s
- Crew Time: 436 hours
- Data Storage: 92 Mbytes
- Racks Occupied On-Orbit: 5 DRE
- Truss Attach Points: 0.7 APs

*Utilization planning guidelines allow the total resources used by NASA's User Sponsors to equal 125%, for the launch minus 5 year timeframe.
OCP SSF Utilization Traffic Model

Space Station Freedom Flight Manifest

- Includes payloads on Mission Build Right 6, currently scheduled for launch in December 1996.
**Office of Commercial Programs**
**Space Station Freedom Payload Heritage**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Zeolite Crystal Growth (ZCG)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Battelle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Applications: Kidney dialysis, radioactive waste cleanup, petroleum processing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Affiliates: Amoco Chemical Co., DuPont, Intek, Teledyne Brown</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Protein Crystal Growth (PCG)  |      |      |      |      |      |      |
| UAB                           |      |      |      |      |      |      |
| • Applications: Human gamma-interferon, ascorbate lyase |
| • Affiliates: Schering-Plough, Burroughs Wellcome, DuPont, Genentech, Vertex, SmithKline & French, Upjohn, Eli Lilly, Eastman Kodak, Biocryl, Space Industries, Inc. |

| Bioregenerative Water System (BWS) |      |      |      |      |      |      |
| WSCAR                           |      |      |      |      |      |      |
| • Applications: Controlled plant growth environments, water regeneration for space application |
| • Affiliates: Quantum Devices, Inc., Phytoforms of America, Inc., Automated Agriculture Assoc., Inc. |

| Module for Integrated Cell Research In Orbit (MICRO) Bioserve |      |      |      |      |      |      |
|                                                             |      |      |      |      |      |      |
| • Applications: Membranes formation, crystal growth, cell cultures, organism growth |
| • Affiliates: Alcoa, Ball, Boeing, Central Biomedica, DuPont, Omni Data, Juvenile Diabetes Foundation |

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**Legend:**
- M: Middeck
- SP: SPACEHAB/Spacelab
- S: Space Station Freedom
- C: COMET
- R: Sounding Rocket
- G: Gas Can

---

**OCP Payload Development and Transition to Space Station Freedom**

- OCP has an active flight program using Middeck, sounding rockets, gas cans, and KC-135s to develop experiments
- OCP intends to extend the flight experiments which are successful on these carriers to the Space Station Freedom
- OCP has a draft traffic model and a flight plan for development flights of payloads on various carriers to get us from the present to the Space Station Freedom time frame
- OCP will rely heavily on the existing carriers plus COMET and SPACEHAB for payload development and transition to Space Station Freedom
Vision

• Stimulating private sector involvement in space-related activities to enhance the competitiveness of U.S. industry, promote the nation’s economic well-being, and improve the overall quality of life
SPACE TECHNOLOGY RESEARCH PLANS

Presented by W. Ray Hook
Director for Space
NASA Langley Research Center

ABSTRACT

Development of new technologies is the primary purpose of the Office of Aeronautics and Space Technology (OAST). OAST’s mission includes the following two goals: (1) to conduct research to provide fundamental understanding, develop advanced technology and promote technology transfer to assure U.S. preeminence in aeronautics and to enhance and/or enable future civil space missions; and (2) to provide unique facilities and technical expertise to support national aerospace needs.

OAST includes both NASA Headquarters operations as well as programmatic and institutional management of the Ames Research Center, the Langley Research Center and the Lewis Research center. In addition, a considerable portion of OAST’s Space R&T Program is conducted through the flight and science program field centers of NASA. Within OAST, the Space Technology Directorate is responsible for the planning and implementation of the NASA Space Research and Technology Program.

The Space Technology Directorate’s mission is “to assure that OAST shall provide technology for future civil space missions and provide a base of research and technology capabilities to serve all national space goals.” Accomplishing this mission entails the following objectives:

• Identify, develop, validate and transfer technology to:
  - Increase mission safety and reliability
  - Reduce flight program development and operations costs
  - Enhance mission performance
  - Enable new missions

• Provide the capability to:
  - Advance technology in critical disciplines
  - Respond to unanticipated mission needs.

In-space experiments are an integral part of OAST’s program and provides for experimental studies, development and support for in-space flight research and validation of advanced space technologies. Conducting technology experiments in space is a valuable and cost effective way to introduce advanced technologies into flight programs. These flight experiments support both the R&T base and the focused programs within OAST.
SPACE TECHNOLOGY RESEARCH PLANS

OVERVIEW

Presented To:
Space Station Freedom Utilization Conference

Presented by:
W. Ray Hook
Director, Space Directorate
Langley Research Center

For:
Office of Aeronautics and Space Technology

August 4, 1992

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
SPACE R&T VISION & MISSION STATEMENT

VISION
WORLD LEADERSHIP IN SPACE RESEARCH AND TECHNOLOGY DEVELOPMENT TO MAKE IT POSSIBLE TO LOOK BEYOND THE KNOWN, TO CHALLENGE THE LIMITS OF HUMAN CAPABILITY, TO INSPIRE THE GENERATION OF THE 21ST CENTURY, AND TO SECURE THE BENEFITS OF SPACE FOR LIFE ON EARTH

MISSION
OAST SHALL PROVIDE TECHNOLOGY FOR FUTURE CIVIL SPACE MISSIONS AND PROVIDE A BASE OF RESEARCH AND TECHNOLOGY CAPABILITIES TO SERVE ALL NATIONAL SPACE GOALS
TECHNOLOGY CONTRIBUTIONS TO SCIENCE SPACECRAFT

- UARS - 205 GHz Limb Sounder Technology
- Shuttle Imaging Radar - SAR Technologies
- TOPEX - Millimeter Accuracy Laser Ranging

- Galileo (Hubble) - CCD Array
- Voyager - Spacecraft Health Monitoring
- Magellan - Radar Ground Processor

Office of Aeronautics and Space Technology

TECHNOLOGY CONTRIBUTIONS TO SPACE PLATFORMS

- Nickel Hydrogen Battery Technology
- NASCAP Spacecraft Charging Model
- Long Duration Exposure Facility
- Life Support Technologies
- Multipropellant Resistojet
- Large Area Solar Cells
- Arcjet Thruster

Office of Aeronautics and Space Technology
TECHNOLOGY CONTRIBUTIONS TO TRANSPORTATION

- Structural Analysis for Solid Rocket Motor (SRM) Redesign
- Vacuum Plasma Spray Coatings & Chambers
- Health Monitoring (Test Facilities)
- Thermal Protection System
- Bearing Cooling Analysis
- Real Time Data System
- Orbiter Experiments
- Damping Seals
- Modified Tires

Office of Aeronautics and Space Technology

UNIVERSITY SPACE ENGINEERING RESEARCH PROGRAM

- UNIVERSITY OF ARIZONA
  - Planetary Resources
- UNIVERSITY OF CINCINNATI
  - Propulsion Monitoring Systems
- UNIVERSITY OF COLORADO, BOULDER
  - Space Construction
- UNIVERSITY OF IDAHO
  - VLSI hardware
- MASSACHUSETTS INSTITUTE OF TECHNOLOGY
  - Controlled Structures Technology
- UNIVERSITY OF MICHIGAN
  - Space TeraHertz Sensing Technologies
- NORTH CAROLINA STATE AT RALEIGH & NORTH CAROLINA AGRICULTURAL & TECHNICAL STATE UNIVERSITIES
  - Mars Mission Technologies
- PENNSYLVANIA STATE UNIVERSITY
  - Propulsion
- RENSSELAER POLYTECHNIC INSTITUTE
  - Robotics

UNIVERSITY-BASED CENTERS

- ATTRACT AND RETAIN STUDENT AND INDUSTRY SUPPORT
- SUPPORT AND EXPAND THE NATION'S ENGINEERING TALENT BASE
- FOSTER INNOVATIVE, MULTI-DISCIPLINARY RESEARCH
SPACE R&T PROGRAM
20-YEAR STRATEGIC VISIONS

Space Science
• Technologies Will Be Ready To Enable Low Mass, Facility Class Single Aperture And Interferometric Space-Based Observatories Across The EM Spectrum; To Conduct Cost-Effective, Long Term Remote Sensing; To Make Complex, But Frequent In Situ Scientific Studies In Space Laboratories, On The Moon & At The Planets; And, To Enhance Human Understanding Of Extremely Large Science Data Sets

Planetary Surface
• The Technology Will be Completed To Emplace Safe and Permanent, Largely Self-Sufficient Human Outposts On The Moon Or Mars, With Capabilities For Extensive Surface Exploration & Science, And Resource Exploitation Operations

Transportation
• Capabilities Will be In Hand To Enable Safe, Highly Operable Reusable Piloted Vehicles For ETO Transport; Low Cost, Reliable Expendable ETO Vehicles For Small, Medium & Large Payloads (including Internationally Competitive ELVs); And Long Life, High Performance Space Transfer Systems That Enable Human Exploration Of The Moon and Mars, And Ambitious Deep Space Robotic Missions

Space Platforms
• Technologies Will Be Ready For Long Lived, Earth Orbiting Platforms With Significantly Reduced Masses and Costs, But Increased Payload Capabilities (Manned & Unmanned); And, For Reduced Mass, High Reliability Spacecraft For Long-Duration Deep Space Science & Exploration Mission Applications

Operations
• New Technology Will Make Possible Largely Autonomous Ground, Flight & In-Space Systems That Reduce The Costs Of Civil Space Mission Operations And Infrastructure, While Improving Their Safety & Reliability, Enabling More Complex Capabilities, And Massively Increasing Mission Data Returns

Innovative Discipline Research
• Innovative, High-Leverage Concepts Will Be Validated Analytically & In Laboratory Research That Make Possible "Next Generation" Earth & Space Science, Exploration, Commercial, And Infrastructure Missions

SPACE FLIGHT RESEARCH & TECHNOLOGY

PROVIDE FOR EXPERIMENT STUDIES, DEVELOPMENT AND SUPPORT FOR IN-SPACE FLIGHT RESEARCH AND VALIDATION OF ADVANCED SPACE TECHNOLOGIES

- IN-SPACE TECHNOLOGY EXPERIMENT PROGRAM (IN-STEP)
  - DESIGN, DEVELOP AND FLIGHT TEST, UNIVERSITY AND NASA TECHNOLOGY FLIGHT EXPERIMENTS

- FLIGHT OPPORTUNITIES VIA
  - SPACE SHUTTLE
  - EXPENDABLE LAUNCH VEHICLES
  - SPACE STATION FREEDOM
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<td>Whisker Reinforced Composites</td>
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<td>Pegana</td>
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<td>Flight Investigation Reentry Environment</td>
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<td>Atlas-Antares</td>
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<td>7/73</td>
<td>Skylab 3</td>
<td>Scout Reentry Heating Project</td>
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<td>Silver Grids Melted in Space</td>
<td>7/73</td>
<td>Skylab 3</td>
<td>Radio Attenuation Measurement</td>
<td>8/61</td>
<td>Hybrid RAM</td>
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**SPACE EXPERIMENTS PROGRAM**

**SCOPE**

- **IN-SPACE EXPERIMENTS ARE AN INTEGRAL PART OF OAST'S PROGRAM**
  - TO OBTAIN DATA THAT CAN NOT BE ACQUIRED ON THE GROUND
  - TO VALIDATE/DEMONSTRATE CERTAIN ADVANCED TECHNOLOGIES
    FEASIBILITY/PROOF OF CONCEPT
    SENSOR/COMPONENT QUALIFICATION

- **FLIGHT EXPERIMENTS SUPPORT BOTH THE R&T BASE AND THE FOCUSED PROGRAMS**

**CONDUCTING TECHNOLOGY EXPERIMENTS IN SPACE IS A VALUABLE AND COST EFFECTIVE WAY TO INTRODUCE ADVANCED TECHNOLOGIES INTO FLIGHT PROGRAMS**
IN-SPACE TECHNOLOGY EXPERIMENTS

MIDDECK 0-GRAVITY DYNAMICS EXPERIMENT (MODE)
MASSACHUSETTS INSTITUTE OF TECHNOLOGY / LaRC

OBJECTIVE:

- TO MEASURE MECHANICAL DYNAMICS OF A JOINTED TRUSS STRUCTURE AND THE SLOSH DYNAMICS OF FLUIDS IN LOW GRAVITY

ACCOMPLISHMENTS:

- COMPLETED STRUCTURAL AND FLUID DYNAMICS TEST OBTAINING 300 MILLION DATA POINTS
  - FOUND NEW MODAL RESONANCES THAT HAD NOT BEEN PREDICTED FROM MODELS DERIVED FROM GROUND BASED DATA
  - FOUND GREATER VISCOSITY EFFECTS THAN MODELS PREDICTED

BENEFITS:

- ADVANCES DESIGN CAPABILITIES FOR:
  - PRECISION CONTROLLED LARGE SPACE STRUCTURES
  - LARGE FLUID MASS FRACTION SPACECRAFT

FIRST FLIGHT STS-48 (MIDDECK)
SEPTEMBER 1991
TOTAL COST: $2.1M
TOTAL WEIGHT: 135 LBS.
GROUND VS. FLIGHT RESULTS FOR STA TORSION MODE

![Graph showing ground vs. flight results for STA torsion mode. The graph plots frequency (Hz) on the x-axis and transfer function magnitude (dB) on the y-axis. The graph includes data points for baseline configuration with PL1 channel 6/Load Cell, showing space and ground configurations with symbols for low and high force.]
TANK PRESSURE CONTROL EXPERIMENT (TPCE)
STS-43 AUGUST 1991

DESCRIPTION

• LOW-G FLUID MIXING EXPERIMENT ON STS
• FREON IN A PLEXIGLASS TANK IS THERMALLY STRATIFIED BY HEATERS CAUSING THE PRESSURE TO RISE
• THEN MIXED BY AN AXIAL JET MIXER TO EQUILIBRATE
• TEMPERATURE, PRESSURE, AND VIDEO DATA

RESULTS

38 TEST RUNS WITH 4 HOURS OF EXCELLENT VIDEO

PRELIMINARY CONCLUSIONS

• FLOW PATTERN WITH CLOSED GEYSER, SHOWN ABOVE, PROVIDES EFFECTIVE PRESSURE CONTROL AND IS MOST EFFICIENT
• THERMAL EQUILIBRATION TIMES AND PRESSURE REDUCTION TIMES IN GENERAL AGREEMENT WITH CERTAIN MODELS
• LOW ENERGY JETS PROVIDE EFFECTIVE AND EFFICIENT PRESSURE CONTROL

ORBITAL ACCELERATION RESEARCH EXPERIMENT (OARE)
LANGLEY RESEARCH CENTER

OBJECTIVE:

• ACCURATE MEASUREMENT OF AERODYNAMIC ACCELERATION ALONG THE ORBITER'S PRINCIPAL AXES IN THE FREE MOLECULAR FLOW REGIME AND THROUGH THE TRANSITIONAL FLOW REGIME DURING REENTRY

APPROACH:

• MEASURES LINEAR ACCELERATIONS (10-9g) IN THE PRESENCE OF ORBITER STRUCTURAL VIBRATION NOISE
• UTILIZES THREE AXIS ELECTROSTATIC ACCELEROMETERS WITH ON-ORBIT CALIBRATION CAPABILITY
• INSTALLED ON THE KEEL BRIDGE FITTING IN THE PAYLOAD BAY
• OPERATIONAL ON OV-102 FLIGHTS 6/92 (STS-50), 6/93 (STS-58)

APPLICATION:

• DETERMINATION OF ORBITAL DRAG WHICH PROVIDES DESIGN SPECIFICATIONS FOR ORBIT MANAGEMENT AND MAINTENANCE SYSTEM FOR THE SSF
• PROVIDES AERODYNAMIC DESIGN DATA FOR ADVANCED AEROMANEUVERING SPACE TRANSFER VEHICLES
• EXPAND KNOWLEDGE OF MICROGRAVITY ENVIRONMENT NEEDED FOR THE CONDUCT OF MICROGRAVITY EXPERIMENTS
ENVIRONMENTAL VERIFICATION EXPERIMENT FOR THE EXPLORER PLATFORM (EVEEP)
GODDARD SPACE FLIGHT CENTER

OBJECTIVE:
• VERIFY ACCURACY OF CONTAMINATION MODELING PROGRAMS

APPROACH:
• FLY TQCM'S ON SPACECRAFT FOR WHICH DETAILED CONTAMINATION MODELS EXIST (EUVE/EXPLORER PLATFORM)
• FLY BOTH TEFOLON-COATED AND UNCOATED TQCM'S IN SUN AND SHADE ORIENTATIONS
• FLIGHT DATE: 6/92 DELTA II (EXPLORER PLATFORM)

APPLICATION:
• FLIGHT RESULTS WILL BE USED TO IMPROVE UNDERSTANDING OF SYNERGISTIC EFFECTS OF UV RADIATION AND ATOMIC OXYGEN ON MATERIALS (TEFLON) AND THE UNDERSTANDING OF VOLATILE MATERIAL DEPLETION MECHANISMS
MAJOR RESULTS OF LDEF FLIGHT EXPERIMENTS

- Meteoroid and debris impacts are not random but affected by meteor showers and space operations
- LDEF data being used to upgrade Meteoroid Model SP-8013 for distribution, velocity, directionality, and surface degradation
- LDEF ionizing radiation studies show induced radioactivity not a significant hazard for Space Station Freedom
- LDEF ionizing radiation data being used to establish crew shielding requirements for Space Station Freedom
- No LDEF systems-level failures attributed to natural LEO environment
- LDEF data established long-term degradation rates for polymeric materials, coatings, composites, and reactive metals in the LEO environment
- LDEF verified that some coatings and materials are resistant to atomic oxygen and UV in the LEO environment
SPACE EXPERIMENTS PROGRAM

SSF PLANNING

• PURPOSE
  - TO ENSURE THAT ADEQUATE SSF RESOURCES WILL BE AVAILABLE FOR OAST USE

• APPROACH
  - DEVELOP TRAFFIC MODEL BASED ON PROJECTED USE
  - DEVELOP REQUIREMENTS FOR DESIGN AND DEVELOPMENT
  - SUPPORT SSF UTILIZATION ACTIVITIES AS REQUIRED
  - SUPPORT BY LaRC, SPACE STATION FREEDOM OFFICE

• STATUS
  - OAST HAS BEEN ALLOCATED 12% OF THE U.S. SHARE OF ALLOCATABLE RESOURCES ON SSF
  - COMPLETED FIRST ANNUAL INPUT TO THE SSF "PARTNER UTILIZATION PLAN" BASED ON TRAFFIC MODEL

• MAJOR NEAR TERM ACTIVITY
  - USE RESULTS OF NEXT A.O. TO PREPARE NEXT YEAR'S INPUT TO "PARTNER UTILIZATION PLAN"

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MODAL IDENTIFICATION EXPERIMENT
LANGLEY RESEARCH CENTER

OBJECTIVE:

• CHARACTERIZE THE STRUCTURAL DYNAMICS OF SPACE STATION FREEDOM AND REFINE MODELING TECHNIQUES FOR FUTURE LARGE SPACE STRUCTURES

APPROACH:

• UTILIZING SPACE STATION FREEDOM HARDWARE TO THE LARGEST EXTENT POSSIBLE WITH THE ADDITION OF OAST SUPPLIED INSTRUMENTATION TO FIT RESEARCH NEEDS, MEASURE SYSTEM MODES IN RESPONSE TO EXCITATION

APPLICATION:

• ON-ORBIT VERIFICATION OF FUTURE LARGE, FLEXIBLE SPACE STRUCTURES FOR SCIENCE AND EXPLORATION
OAST ANNOUNCEMENT OF OPPORTUNITY
SPACE EXPERIMENTS PROGRAM

• PURPOSE
  TO SOLICIT PROPOSALS FOR EXPERIMENTS IN THE TECHNOLOGY CATEGORIES
  - SPACE MATERIALS, COATINGS, AND ENVIRONMENTAL EFFECTS
  - CRYOGENIC FLUID HANDLING
  - HUMAN SUPPORT
  - SPACE POWER
  - IN-SPACE CONSTRUCTION, REPAIR, AND MAINTENANCE
  - SCIENCE SENSORS AND SENSOR COOLING
  - VIBRATION ISOLATION
  - SPACE COMMUNICATION

• APPROACH
  - APPROXIMATELY FIFTY PROPOSALS SELECTED BY RIGOROUS REVIEW PROCESS FOR PHASE A
  - DOWN-SELECTION TO PHASE B, LEADING TO NON-ADVOCATE REVIEW
  - NEW EXPERIMENTS READY FOR FLIGHT STARTING 1997
  - ANY SUITABLE CARRIER UTILIZED, INCLUDING SSF, SHUTTLE, ELV

• STATUS
  - EXPECTED RELEASE IN AUGUST
OSSA SPACE STATION FREEDOM SCIENCE UTILIZATION PLANS

Presented by Dr. Philip J. Cressy
Office of Space Science and Applications
NASA Headquarters

ABSTRACT

Long duration exposure to an essentially zero-gravity environment is a phenomenon exclusive to the Space Station Freedom that cannot be duplicated on Earth. The Freedom Station will offer periods of time on orbit extending to weeks and months rather than hours or days, allowing for in-depth space-based research and analysis to a degree never before achieved. OSSA remains committed to exploiting the unique capabilities provided by the Space Station as well as other space-based facilities to study the nature of physical, chemical, and biological processes in a low-gravity environment and to apply these studies to advance science and applications in such fields as biomedical research, plant and animal physiology, exobiology, biotechnology, materials science, fluid physics, and combustion science. The OSSA focus is on progressive science investigations, many requiring hands-on scientist involvement using sophisticated experiment hardware. OSSA science utilization planning for the Freedom Station is firmly established. For this presentation, this planning is discussed in three general areas: OSSA goals and overall approach, the current and ongoing program, and plans for space station utilization. In the first area, OSSA addresses its overall approach to space science research, its commitment to transition to Space Station Freedom, and its top-level strategy for the utilization of Freedom. The current and ongoing program is next discussed, focusing on the various Spacelab series of missions which are providing the stepping-stones to Space Station Freedom. Selected science results from SLS-1 and USML-1 are cited which underline the value of properly outfitted laboratories in space in which crew-intensive experiment interactions are possible. The presentation is concluded with a discussion of top-level goals and strategies for utilizing the Freedom Station by OSSA’s Life Sciences Division and its Microgravity Science and Applications Division.
OFFICE OF SPACE SCIENCE AND APPLICATIONS GOALS

- To advance scientific knowledge of the planet Earth, the solar system and the universe

- To use the unique vantage point and environment of space to study the universe, to understand the factors that influence our planet's environment, and to solve practical problems on Earth

- To expand the human presence beyond the Earth into the solar system
EVOLVING U.S. SPACE SCIENCE CAPABILITIES

SOUNDING ROCKETS AND BALLOONS
- ASTRONOMY
- PLASMA PHYSICS

FREE FLYING OBSERVATORIES
- ASTRONOMY
- PLASMA PHYSICS
- PLANETARY

SKYLAB
- ASTRONOMY
- LIFE AND MATERIALS SCIENCES

SPACELAB
- LIFE AND MATERIALS SCIENCES
- OBSERVING SCIENCES

SPACE STATION
- LIFE SCIENCES
- MICROGRAVITY SCIENCES
- ATTACHED PAYLOADS

1940s 1950s 1960s 1970s 1980s 1990s 2000s 2010s

TRANSITION TO SPACE STATION

BEGINNING WITH SPACELAB AND OTHER IN-SPACE FACILITIES, WE ARE MOVING AGGRESSIVELY, BUT SENSIBLY, TO DEVELOP THE PRINCIPAL AREAS OF SPACE SCIENCE AND APPLICATIONS THAT WILL TAKE ADVANTAGE OF UNIQUE FREEDOM STATION OPPORTUNITIES, FOR MICROGRAVITY SCIENCE AND LIFE SCIENCES RESEARCH IN PRESSURIZED LABORATORIES.

OSSA STRATEGIC PLAN 1991
OSSA STRATEGY

- PLAN UTILIZATION TO SUPPORT PREPARATION FOR HUMAN EXPLORATION
- EMPHASIZE PRESSURIZED VOLUME UTILIZATION
  - Life Sciences
  - Microgravity Science and Applications
- TRANSITION SENSIBLY FROM SPACELAB TO SPACE STATION
- ENSURE A RANGE OF UTILIZATION OPTIONS
  - Facility-Class Payloads
  - Middeck and Drawer-Class Payloads
  - Small and Rapid Response Payloads
  - Attached (Observational) Payloads
- SOLICIT FIRST-CLASS SCIENCE
  - Planned AOs and NRAs
  - International Collaborations
- INTEGRATE THE INTERESTS OF THE U.S. SCIENCE COMMUNITY

THE CURRENT PROGRAM

OSSA IS LAYING THE FOUNDATION FOR SPACE STATION FREEDOM WITH ITS SPACELAB SERIES OF MISSIONS

SLS - Spacelab Life Sciences missions dedicated to human, animal, plant, and cell research

USML - US Microgravity Laboratory missions dedicated to materials, fluids, and combustion research

IML - International Microgravity Laboratory missions which emphasize international cooperation in microgravity research
SOME RECENT SCIENCE RESULTS

SLS-1
- RAPID TRANSITION IN MUSCLE ACTIVITY AWAY FROM MUSCLES THAT CONTROL WALKING AND POSTURE
- SHIFTS IN MUSCLE NUTRIENT USAGE TO MORE CARBOHYDRATES AND LESS FAT
- IMPAIRMENT OF BLOOD PRESSURE REGULATORY MECHANISMS
- UNEXPLAINED RETENTION OF 1-g LUNG CHARACTERISTICS IN 0-g
- UNEXPECTED INCREASED BLOOD FLOW TO THE KIDNEYS

USML-1
- SEVERAL INORGANIC CRYSTALS APPEAR TO BE LARGEST AND HIGHEST QUALITY GROWN TO DATE
- OVER 700 CREW MANIPULATIONS OF PROTEIN CRYSTAL SAMPLES INCREASED QUALITY AND YIELD
- MANY CRYSTALS WERE OBSERVED TO BEGIN GROWING ONLY LATE IN THE FLIGHT
- MANY UNPLANNED/UNEXPECTED RESULTS WERE OBTAINED

LIFE SCIENCES STRATEGY

PHASE I
- Focus on Monitoring Human Health and SSP Environment

PHASE II
- Build Upon Established Infrastructure to Provide a New SSP National and International Life Sciences Research Capability

PHASE III
- Provide International Life Science Research Facility for In-Depth Studies Over Dedicated Periods of Time
- Address Medical Issues Relating to Space Exploration Missions Involving Humans
microgravity science and applications strategy

man-tended transition hardware

phase i
- use shuttle status transition hardware
- conduct experiments in microgravity science, combustion science, and protein crystal growth

man-tended facility class hardware

phase ii
- increased use of station facility class hardware
- continue research begun in phase i but address more mature questions
- begin studies in fluid physics
- begin use of small and rapid response payloads

permanent manned presence

phase iii
- conduct experiments requiring long periods of manned interaction
- address more complex questions in all research areas

evolution to man-tended free flyers

space station milestones

- free element launch
- man-tended capability
COMMERCIAL RESEARCHER PERSPECTIVE

Presented by Dr. Larry DeLucas
Center for Macromolecular Crystallography
University of Alabama at Birmingham

ABSTRACT

Protein crystallography — a research tool used to study the structure of the complex building blocks of living systems — has a lot to gain from space-based research. In order to know how a protein works in the human body, researchers must understand its molecular structure. Researchers have identified 150,000 different proteins in the body, but they now know the structure of less than a third of them.

The only viable technique for analyzing the structure of these proteins is x-ray diffraction of the proteins in their crystal form. The better the quality of a protein crystal, the more useful it is to researchers who are trying to delineate its structure. The microgravity environment of space allows protein crystals to grow nearly undisturbed by convection and other gravity-driven forces that cause flaws to form in them on the ground. In space, lack of convection enables protein crystals to grow more slowly than they do on Earth, and the slower a protein crystal grows, the fewer flaws it will have.

Protein crystal growth experiments have already flown on 14 Space Shuttle missions. This year’s USML-1 Spacelab mission included protein crystal growth experiments conducted for commercial researchers. The results of protein crystal experiments flown thus far have been larger crystals with more uniform morphologies.

The Center for Macromolecular Crystallography (A NASA-cosponsored CCDS) currently builds flight hardware to meet researchers’ needs and handles sample loading and retrieval for flight experiments.

Protein crystallography enables “rational drug design”: the development of drugs that bind only with the target protein and, hence, do not cause side effects. For example, pharmaceutical companies presently are interested in developing drugs that can inhibit purine nucleoside phosphorylase (PNP), a protein that plays a role in auto-immune diseases. To continue these kinds of investigations, researchers need a constant supply of protein crystals that are as free of flaws as possible.

Space Station Freedom will provide the kind of research environment that will enable the production of such supplies. In addition, Freedom will provide the kind of long-duration facility required by protein crystal researchers: 40 percent of proteins require more than two weeks to crystallize.
Need for Microgravity Environment

- 450 protein structures completed
- Molecular biology
- Rational drug design
- Large co-investigator group from universities and industries
- No other technique
### Morphometry

Number of Crystals Sampled, PCF
STS 37, 43, 49

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<th>GROUND ROSETTE</th>
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<td>405</td>
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<td>na</td>
<td>1155</td>
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<td>1220</td>
<td>1232</td>
<td>328</td>
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Morphometry
Length of Single Crystals
STS 37, 43, 49

![Graph showing the relationship between PCF volume (ml) and millimeters for FLIGHT and GROUND conditions for STS 37, 43, and 49.]
X-Ray Diffraction

Intensity as Function of Crystal Volume
STS-49: 500ml PCF

Means for 8 Flight and 7 Ground Crystals

Intensity: Flight > Ground, 0.0005 level
Volume: Flight = Ground
X-Ray Diffraction
Number of Crystals Sampled, PCF
STS 37, 43, 49

<table>
<thead>
<tr>
<th>SHUTTLE FLIGHT</th>
<th>GROUND</th>
<th>FLIGHT</th>
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<tr>
<td>STS 37</td>
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<td>5</td>
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<td>STS 43</td>
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<td>10</td>
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<td>STS 49</td>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td>TOTAL</td>
<td>53</td>
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</table>

**Easy Access**

- We build hardware to meet science group’s needs
- We handle loading and sample retrieval
- Sample approval process is rapid and can be accomplished late in flow
Constant Access/Rapid Turnaround

• Need laboratory around the clock

• Need constant supply of crystals

• Crystals must be harvested frequently

• New protein batches transferred via frequent and consistent shuttle schedule

Dynamic and Flexible Hardware Program

• Facility capable of rapidly meeting needs of each corporate partner

• Thermal Enclosure System (TES)

• Protein crystal growth organizational chart

• Hardware development
  • Science objectives
  • Design/analysis
  • Manufacturing
  • Qualification testing (for flight)
  • Functional testing (to meet science objectives)
  • Verification
Consistency/Predictable Schedule

- Corporate/Academic Planning
- Reliability

Real Time Monitoring and Control

- Scientists on board full time
- Observation/Crystal Optimization
JAPANESE PLAN FOR SSF UTILIZATION

Toshio Mizuno
National Space Development Agency of Japan

ABSTRACT

The JEM program has made significant progress. The JEM PDR was completed in July 1992; construction of JEM operation facilities has begun; and the micro-G airplane, drop shaft, and micro-G experiment rocket are all operational. The national policy for JEM utilization was also established. The Space Experiment Laboratory (SEL) opened in June '92 and will function as a user support center. Eight JEM multiuser facilities are in phase B, and scientific requirements are being defined for 17 candidate multiuser facilities. The National Joint Research Program is about to start. Precursor missions and early Space Station utilization activities are being defined.
Japanese Plan for SSF Utilization

T. Mizuno
August 4, 1992
Huntsville Alabama
CONTENTS

1. JEM Program Budget Status
2. JEM Utilization Policy Status
3. JEM Development Status
4. JEM Operations Capability Development Status
5. Status of Ground Research to Develop Generic Experiment Support Technology
6. Status of User Support Center Construction
7. Multiuser Facility Development Status
8. Organization National Joint Research Using Space Environments
9. Status of Precursor Mission and JEM Early Utilization Definition
10. Other Topics
1. JEM Program Budget Status (JFY1992)

1.1. JEM Development

(JEM EM, JEM multiuser experiment facility, TR-1A, etc.)

¥33.7B (~262M$)*

¥24.6B (~190M$)

1.2. JEM Operations Preparation

(JEM Operations facility, Crew training facility, etc.)

¥4.2B (~32M$)*

¥3.0B (~23M$)

@1 Dollar = 129 yen

* Multiyear government guarantee for appropriation

2. JEM Utilization Policy

2.1. Report by SAC SS panel was issued in April 1992.

2.2. Report addresses the following:

(1) Need of national research program for promoting JEM Utilization.

(2) Importance of developing multiuser facilities Identification of facility list and development policy.

(3) Cost sharing by users consistent with JEM and multiuser facility verification/operation phase.

(4) Identification of AO issues and experiment selection timing and frequency.

(5) Importance of precursor missions.
AO. Experiment Selection, PUP/CouP/Top

TIME (year)

\[ X''-5 \quad X''-4 \quad X''-3 \quad X''-2 \quad X''-1 \quad X'' \]

\[ \text{PUP} \quad \text{COUP} \quad \text{TOP} \]

Reference Mission Set

Selected Mission Set (Baseline Mission)

Screened Experiments Group

Ground Research & Precursor Flight Experiment

NASDA

3. JEM Development Status

3.1. JEM PDR

Contractor PDR January to March 1992

System PDR June to July 1992

3.2. Technology Development Test

JEM Maintenance and Repair simulation using MSFC WETF in Nov. 1991

3.3. Engineering Model (EM) and Proto-Flight Model (PFM)

EM Contracts started in March 1991

PFM budget request is being prepared

3.4. Construction of JEM Test Facility at TKSC

Construction starts in summer 1992
### JEM Development Schedule

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<td>4 8 12</td>
<td>4 8 12</td>
<td>4 8 12</td>
<td>4 8 12</td>
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<td>Milestone</td>
<td>NASA PDR</td>
<td>NASA MTC CDR</td>
<td>JEM PDR</td>
<td>JEM CDR</td>
<td>FEL</td>
<td>JEM Launch</td>
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<td>Activity Phase</td>
<td>Phase B</td>
<td>Phase C/D</td>
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</tr>
</tbody>
</table>

#### JEM Development

- Development Testing
- EM Integration and Testing
- PFM Integration and Testing

#### JEM Operation System

- System Design
- Detailed Design & Development
- Integration & Training
- Operation

<table>
<thead>
<tr>
<th>PDR</th>
<th>Preliminary Design Review</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDR</td>
<td>Critical Design Review (#1, Interface; #2, JEM)</td>
</tr>
<tr>
<td>EM</td>
<td>Engineering Model</td>
</tr>
<tr>
<td>PFM</td>
<td>Proto Flight Model</td>
</tr>
</tbody>
</table>

---

### 4. JEM Operations Capability Development Status

#### 4.1. Design of JEM Operations System

- **PRR** March 1991
- **System Review** Oct. 1993

#### 4.2. Crew Recruiting
- MS candidate was selected in April 1992
- SS/SO will be recruited every two years

#### 4.3. Construction of JEM Operations Facility
- Weightless Environment Test Facility construction started in March 1992
- Astronaut Training Facility Construction will start in summer 1993
- Construction of SS Operations Facility (Regional Operation Center for JEM) will start in summer 1993
4.4. Development of JEM Operations Planning system
   - Strategic/Tactical planning software and database are being defined

4.5. JFD (JEM Flight Demonstration)
   - JEM Manipulator servicing capability demonstration test will be held in 1996 using STS

5. Status of Ground Research to Develop Generic Experiment Support Technology (GEST)

5.1. Drop Shaft/Drop Tube
   - JAMIC Facility (10 sec. μ–G) has been operational since 1991
   - MGLAB Facility (4.5 sec. μ–G) will be operational in 1993

5.2. GEST Development using μ–G Airplane (MU–300 Business Jet)
   - Routine 6 month/year parabolic flight since Sep. 1990

5.3. GEST Development using TR–1A Rocket
   - Successful first flight in Sep. 1991
   - Next flight in Aug. 1992
### Themes and Co-investigators of TR-IA Rocket Microgravity Experiments Program

<table>
<thead>
<tr>
<th>Experiment Module</th>
<th>TR-IA No.1</th>
<th>TR-IA No.2</th>
<th>TR-IA No.3</th>
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<tbody>
<tr>
<td>Module for Experiment Observation Technologies</td>
<td>Field observation of boundary and environment phase in crystal growth</td>
<td>Marangoni convection generation and control</td>
<td>Bubble generation, growth and movement</td>
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<td></td>
<td>Katsuo Tsukamoto (Tohoku U), Kazuhiko Kuribayashi (ISAS), Tsutomu Sawada (NIRIM)</td>
<td>Hisao Azuma (NAL), Akira Hirata (Waseda U), Keiichi Kuwahara (IHI)</td>
<td>Yoshiyuki Abe (Electrotechnical Lab), Masamichi Ishikawa (MRI), Shinya Ishii (MHI)</td>
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<tr>
<td></td>
<td>(Not applicable)</td>
<td>(Not applicable)</td>
<td>(Not applicable)</td>
</tr>
<tr>
<td>Temperature-gradient Furnace (TGF)</td>
<td>(Not applicable)</td>
<td>Melting and solidification of high-temperature oxide superconductor Kazuma Togano (NRIM)</td>
<td>Melting and solidification of vitreous material Junji Hayakawa (GIRIO)</td>
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<tr>
<td>High-temperature Furnace (HTF)</td>
<td>Melting and solidification of high-temperature oxide superconductor Kazuma Togano (NRIM)</td>
<td>(Not applicable)</td>
<td>(Not applicable)</td>
</tr>
</tbody>
</table>

### TR-IA MISSION PROFILE

- **Beginning of the experiment**: 110 km - t+80 sec
- **End of the experiment**: t+441 sec
- **Rate Control**: Payload Sep., Burn out
- **Parachute Dep.**
- **Telemetry**
- **NASDA TNSC**

6.1. NASDA Space Experiment Laboratory (SEL) at TKSC
   - SEL plays an integral role for Japanese USCs
   - SEL became operational in June 1992

6.2. Discipline USCs Concept
   - Major National Institutes are expected to function as discipline-oriented User Support Center
     E.G. NAL for Fluid physics
     NIRIM for Inorganic Materials
     NRIM for Metals
     ISAS for Astronomical Observations

6.3. Telescience Technology Application
   - Telescience technology will be applied to link NASDA SEL and Discipline Centers
7. Onboard Multi-User Facility (MUF) Development Status

7.1. Selection of MUF

- MUF Candidate List was completed by Pre-AO survey
  List includes three categories, a definitive one, one which needs to be coordinated among international partners, and one which needs to reflect each year's AO

- JEM EM system/MUF verification test

- JEM traffic model study identifies early stage of MUF
7.2. Technology Development Status
- 5 MUF technology development will continue until early 1993

7.3. Requirements Update by User Advisory G
- 9 Advisory groups were established
- Requirement update will be completed by summer 1992

7.4. Coordination among International Partner
- Multilateral (MUWG)
- Bilateral

8. Organized National Joint Research using Space Environments

8.1. Significance of the Joint Research
- Enhance research by coordinating/complementing research among national institutes, universities, private sectors
- Easy to accommodate experiments in SS

8.2. Joint Research Plan
- STA authorizes the Joint Research (Core Research)
- NASDA develops experiment technology and offers space flight chance
- Assigned Institute for Core Research conducts the research management
  E.G. NAL, NIRIM, NRIM
- JSUP supports general management of the Joint Research
- The plan will be implemented in mid 1992 and will evolve step-by-step
9. Status of Precursor Mission and JEM Early Utilization of Definition

9.1. Space Experiment Status

(1) TR–1A sounding rocket
   #1 Sep. 1991, #2 Aug. 1992, #3 Summer 1993
   follow-on flights are under study

(2) IML–1
   Jan. 22, 1992, 2 NASDA Experiments

(3) FUWATT '92 (SL–J/FMPT)
   Sep. 1992, 34 Japanese Experiments

(4) SFU
    Feb.–June 1994

(5) IML–2
    July 1994, 12 Japanese Experiments
9.2. Definition of follow-on Precursor Mission

(1) Preliminary study of Follow-on TR-1A flight, E1 participation, Spacehab Utilization
(2) Dialogue with international partners for potential cooperation

9.3. Definition of Early Utilization of the Space Station

(1) Traffic model study of JEM early utilization
(2) Dialogue with international partners for potential cooperation

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### JEM Early Utilization Traffic Model (as of June 1992)

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<td><strong>MB12 (JEM #1)</strong></td>
<td>UF5</td>
<td>UF6</td>
<td><strong>MB15 (JEM #2)</strong></td>
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<td>IF</td>
<td>↑</td>
<td>Clean ↑</td>
<td>ISGS ↑</td>
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<tr>
<td>GHF</td>
<td>↑</td>
<td>(norm. Temp)</td>
<td>SEMS ↑</td>
</tr>
<tr>
<td>ZMF</td>
<td>↑</td>
<td>PSAS ↑</td>
<td>LF ↑</td>
</tr>
<tr>
<td>PCF</td>
<td>↑</td>
<td></td>
<td>SPSS ↑</td>
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<tr>
<td><strong>LSE</strong></td>
<td>Image processor</td>
<td>Refrigerator ↑</td>
<td>PSAS ↑</td>
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<tr>
<td><strong>UP mass</strong></td>
<td>~2.5DRE</td>
<td>~0.75DRE</td>
<td>~1DRE</td>
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<tbody>
<tr>
<td><strong>IF</strong></td>
<td>Isothermal Furnace</td>
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<td></td>
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<tr>
<td><strong>SGF</strong></td>
<td>Solution Growth Facility</td>
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<tr>
<td><strong>PCEF</strong></td>
<td>Physics and Chemistry Experiment Facility</td>
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<tr>
<td><strong>CCF</strong></td>
<td>Cell Culture Facility</td>
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<td><strong>GHF</strong></td>
<td>Gradient Heating Furnace</td>
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<tr>
<td><strong>SAHF</strong></td>
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<td><strong>PCF</strong></td>
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<td>Fluid Physics Experiment Facility</td>
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<td><strong>LF</strong></td>
<td>Levitation Furnace</td>
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<td><strong>PSAS</strong></td>
<td>Physiological Signal Acquisition System</td>
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<td><strong>SEMS</strong></td>
<td>Space Environment Measurement System</td>
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<td><strong>SPSS</strong></td>
<td>Small Payload Support System</td>
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<tr>
<td><strong>SCF</strong></td>
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<td><strong>VGF</strong></td>
<td>Vapor Growth Facility</td>
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</tbody>
</table>

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**NOTES:**
- IF: Isothermal Furnace
- SGF: Solution Growth Facility
- PCEF: Physics and Chemistry Experiment Facility
- CCF: Cell Culture Facility
- GHF: Gradient Heating Furnace
- ISCS: Intersatellite Communication System
- TES: Teleoparation Experiment System
- EOT: Earth Observation TEST
- SAHF: Small Animal Holding Facility
- ZMF: Zone Melting Furnace
- PCF: Protein Crystallization Facility
- FPEF: Fluid Physics Experiment Facility
- LF: Levitation Furnace
- PSAS: Physiological Signal Acquisition System
- SEMS: Space Environment Measurement System
- SPSS: Small Payload Support System
- SCF: Separation Centrifuge Facility
- EPF: Electrophoresis Facility
- VGF: Vapor Growth Facility

---

**JEM PM Experiment Racks Installation Model**

- **Isotermal Furnace**
  - IDU
  - FPDR
- **Image Processor**
- **Zone Melting Furnace**
  - IDU
  - FPDR
- **Gradient Heating Furnace**
  - IDU
  - FPDR
- **Levitation Furnace**
  - IDU
  - FPDR

---

**Protein Crystallization Facility**

**Physiological Signal Acquisition System**

**Clean bench**

**Cell Culture Facility**

**Separation Centrifuge Facility**

**Refrigerator/Freezer**

**Inter-satellite Communication System**

**User Storage Rack (PM ceiling)**

**User Storage Rack (ELS-PS)**
10. Other Topics

(1) Space Experiment Data Base Development Status
   - Data Base in Japanese became operational in June 1992
   - Data Base in English will be operational in mid 1993

(2) Telescience Test Bed
   - Telescience Test Bed was installed in NASDA SEL in June 1992
   - Telescience Demonstration Test for JEM MTC operation will be in Nov. 1992
CANADIAN SPACE AGENCY SPACE STATION FREEDOM UTILIZATION PLANS

Presented by James Faulkner and Ron Wilkinson
Canadian Space Agency

ABSTRACT

Under the terms of the NASA/CSA Memorandum of Understanding, Canada will contribute the Mobile Servicing System and be entitled to use 3% of all Space Station utilization resources and user accommodations over the 30 year life of the Station. Equally importantly Canada, like NASA, can begin to exploit these benefits as soon as the Man-Tended Capability (MTC) phase begins, in early 1997.

Canada has been preparing its scientific community to fully utilize the Space Station for the past five years; most specifically by encouraging, and providing funding, in the area of Materials Science and Applications, and in the area of Space Life Sciences. The goal has been to develop potential applications and an experienced and proficient Canadian community able to effectively utilize microgravity environment facilities such as Space Station Freedom. In addition, CSA is currently supporting four facilities; a Laser Test System, a Large Motion Isolation Mount, a Canadian Float Zone Furnace, and a Canadian Protein Crystallization Apparatus.

In late April of this year CSA sent out a Solicitation of Interest (SOI) to potential Canadian user from universities, industry, and government. The intent of the SOI was to determine who was interested, and the type of payloads which the community at large intended to propose.

The SOI will be followed by the release of an Announcement of Opportunity (AO) following governmental approval of the Long Term Space plan later this year, or early next year. Responses to the AO will be evaluated and prioritized in a fair and impartial payload selection process, within the guidelines set by our international partners and the Canadian Government.

Payload selection is relatively simple compared to the development and qualification process. An end-to-end user support program is therefore also being defined. Much of this support will be provided at the new headquarters currently being built in St. Hubert, Quebec.

It is recognized that utilizing the Space Station could be expensive for users; costing in many cases millions of dollars to get a payload from conception to retrieval. It is also recognized that some of the potential users cannot or will not invest a lot of money or effort into Space Station utilization, unless there is a perceived significant commercial potential. How best to fund Space Station payloads is under study.

Space Station Freedom will provide the first opportunity for Canada to conduct experiments in a long-duration microgravity environment. CSA have been developing and funding potential users for some time, and considerable interest has been shown by the response to our SOI earlier this year. Canada can be one of the two earliest users for the Space Station, along with NASA. We hope to take full advantage of this opportunity.
MOBILE SERVICING SYSTEM:
MSC and SPDM

- Space Station Remote Manipulator (SSRMS)
- Power Data Grapple Fixtures (4) (PDGFs)
- MBS Camera
- Special Purpose Dexterous Manipulator (SPDM)
- MBS Avionics Boxes
- MT Batteries
- Space Station Truss Structure
- Mobile Transporter (MT) (Envelope)
### SPACE STATION ALLOCATIONS

<table>
<thead>
<tr>
<th>1. Utilization Resources (power, crew time, etc)</th>
<th>CSA</th>
<th>ESA</th>
<th>Japan</th>
<th>NASA</th>
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<tbody>
<tr>
<td>Utilization Resources</td>
<td>12%</td>
<td>12%</td>
<td>12%</td>
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<tr>
<td>2. User Accommodations</td>
<td>CSA</td>
<td>ESA</td>
<td>Japan</td>
<td>NASA</td>
</tr>
<tr>
<td>a. NASA Lab Module</td>
<td>3%</td>
<td>3%</td>
<td>3%</td>
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</tr>
<tr>
<td>b. NASA Truss Attach Points</td>
<td>3%</td>
<td>3%</td>
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<tr>
<td>c. ESA Attached Pressurized Module</td>
<td>3%</td>
<td>3%</td>
<td>3%</td>
<td>3%</td>
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<tr>
<td>d. Japanese Experimental Module</td>
<td>3%</td>
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<tr>
<td>e. NASA Polar Platform</td>
<td>3%</td>
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<tr>
<td>f. ESA Polar Platform</td>
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<td>3%</td>
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<td>3. Supporting Services</td>
<td>CSA</td>
<td>ESA</td>
<td>Japan</td>
<td>NASA</td>
</tr>
<tr>
<td>a. Space Shuttle launch and return services</td>
<td>3%</td>
<td>3%</td>
<td>3%</td>
<td>3%</td>
</tr>
<tr>
<td>b. TDRSS data transmission capacity</td>
<td>3%</td>
<td>3%</td>
<td>3%</td>
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### CANADIAN SHARE OF RESOURCES AND ACCOMMODATIONS

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<tr>
<th></th>
<th>1997</th>
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<tbody>
<tr>
<td>Pressurized Upmass (kg)</td>
<td>385</td>
<td>334</td>
<td>210</td>
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<tr>
<td>Up-Volume (racks)</td>
<td>0.8</td>
<td>0.6</td>
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<td>On-board Racks</td>
<td>0.5</td>
<td>0.8</td>
<td>1.5</td>
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<tr>
<td>Unpressurized Upmass (kg)</td>
<td>372</td>
<td>372</td>
<td>248</td>
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<tr>
<td>External Attachment Points</td>
<td>0.1</td>
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<tr>
<td>Average Power (Kw)</td>
<td>0.26</td>
<td>0.46</td>
<td>0.72</td>
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<tr>
<td>Total Crew Time (hrs)</td>
<td>39</td>
<td>39</td>
<td>26</td>
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<tr>
<td>On-board Data Storage (MB)</td>
<td>8</td>
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<tr>
<td>Average Down Link (Mbps)</td>
<td>0.93</td>
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(1)The 1999 figures include allocations up to Sep 1999 (i.e. PMC)
USER DEVELOPMENT PROGRAM

- MATERIALS SCIENCES AND APPLICATIONS
- SPACE LIFE SCIENCES
- GOAL: TO DEVELOP A CANADIAN COMMUNITY ABLE TO EFFECTIVELY UTILIZE MICROGRAVITY ENVIRONMENT FACILITIES SUCH AS SPACE STATION

MATERIALS SCIENCES AND APPLICATIONS

- EXPLORATION
  - UNIQUE PHENOMENA
- FUNDAMENTAL SCIENCES
  - FLUID PHYSICS
  - TRANSPORT PHENOMENA
  - CONDENSED MATTER PHYSICS
  - COMBUSTION SCIENCE
  - NUCLEATION
  - CRYSTAL GROWTH
- APPLIED SCIENCE
  - MATERIAL SCIENCE
  - PROTEIN CRYSTALLIZATION
  - LASER MATERIAL PROCESSING
- TECHNOLOGY
  - DEMONSTRATE HARDWARE
SPACE LIFE SCIENCE

- HUMAN PHYSIOLOGY
- GRAVITATIONAL BIOLOGY
- BIOTECHNOLOGY
- THREE COMPONENTS:
  - INVESTIGATOR DEVELOPMENT
  - SPACE STATION PREPARATORY SCIENCE
  - SPACE STATION

USER DEVELOPMENT
PROGRAM FACILITIES

- LASER TEST SYSTEM
- LARGE MOTION ISOLATION MOUNT
- CANADIAN FLOAT ZONE FURNACE
- CANADIAN PROTEIN CRYSTALLIZATION APPARATUS
SOLICITATION OF INTEREST

- MATERIALS RESEARCH 52%
- BIOLOGY, LIFE SCIENCES, BIOTECHNOLOGY 17%
- ROBOTICS, SPACE STRUCTURES, DEVICES 12%
- EARTH OBSERVATION, ATMOSPHERIC RESEARCH 8%
- HARDWARE DEVELOPMENT 7%
- COMMUNICATIONS, ENERGY 4%

REVIEW PANELS

- REPRESENTATIVES FROM UNIVERSITY, INDUSTRY, GOVERNMENT
- FOUR PANELS TO START:
  - SCIENCE (including related technology);
  - SPACE TECHNOLOGY (e.g. structures, devices, robotics);
  - EARTH OBSERVATION; and
  - COMMUNICATIONS.
REVIEW PANEL EVALUATION CRITERIA

- SCIENTIFIC MERIT
- ORIGINALITY
- VALUE TO CANADA
- STATION RESOURCES REQUIRED
- COMMERCIAL POTENTIAL
- COST

CANADIAN SPACE STATION PROGRAM
ALLOCATION BOARD (CSSPAB)

- CSA VICE PRESIDENT OPERATIONS (Chairman)
- CSA VICE PRESIDENT RESEARCH & APPLICATIONS
- DIRECTOR GENERAL CANADIAN SPACE STATION PROGRAM
- DIRECTOR GENERAL SPACE SCIENCE
- CSA USER OPERATIONS PANEL MEMBER
  plus
- CHAIRMEN OF REVIEW PANELS (to relevant meetings)
USER SUPPORT PROGRAM

- ASSISTANCE TO PI'S
- TECHNICAL SUPPORT CENTERS
- SPECIALIZED EQUIPMENT
- ARRANGE LAUNCH AND COMMUNICATIONS SERVICES
- PAYLOAD INTEGRATION CENTER
- PAYLOAD OPERATIONS CENTER
- PAYLOAD SUPPORT CENTER

FUNDING POLICIES

- TO BE DETERMINED
- INITIAL THOUGHTS:
  - CSA would subsidize the costs associated with integrating, qualifying, launching, controlling, and recovering payloads;
  - PI's absorb some of the payload development costs by contributing in-kind support, or by obtaining funding from other sources; and
  - where there are future commercial returns, the federal government would apply user fees to recover some portion of the costs.
EUROPEAN RESEARCH PLANS
Presented by Jean-Jacques Dordain
Head of Microgravity and Columbus Utilisation Department
European Space Agency

SPEECH

It is difficult to say in 30 minutes what we shall do in the next 30 years, since the Space Station will be used up to the year 2025, which means that the majority of users are still in school and even some of them are not yet born.

It is also difficult to speak after almost ten speakers about the same subject. As a matter of fact, the European plans on Space Station utilisation are very similar to the plans of the other partners - we have the same hopes and we have the same problems - but we are trying to contribute significantly in the following challenge: How to make the Space Station not only beautiful, but also useful?

Finally, I would like to recall that the European part of the Space Station Freedom is called Columbus, which means a lot!

- Christopher Columbus was truly a European, born in Italy and sponsored by Spain.
- Christopher Columbus established the first link between Europe and America.
- Christopher Columbus opened a new era even though he did not know that he was doing so.

The success for the Space Station would be that future historians could distinguish the pre-Freedom period as they did for the pre-Columbian period.

I shall limit my presentation today to the three following aspects:
1. Why Columbus and, more generally, the Space Station Freedom is a unique tool for Science?
2. What are the capabilities offered by Columbus to the users, in terms of accommodation capabilities and environment?
3. Columbus utilisation has already started, through Precursor Flights: IML-1, ATLAS, EURECA-1 in 1992, Spacelab D-2 next year, later on EURECA-2 and -3, IML-2, SPACELAB E-1 and we are also looking for using the MIR Station and Spacehab, which means any opportunity to prepare the Space Station utilisation and also through ground testbeds. Columbus utilisation is very active on ground. I shall show you pictures of the real stuff and not only artists’ concepts and plans. You can visit the Space Station mock-up here in Huntsville; you are all welcome to visit and use the Columbus facilities at ESTEC in the Netherlands.

First Aspect, the Columbus elements will be used as laboratories, which means a place where we are providing capabilities for doing experiments, i.e. power, computers, ... and as space laboratories, which means a place where we are taking benefit of the space environment, i.e. altitude, vacuum and microgravity. It must be pointed out that scientific utilisation is not the only driver for developing the Columbus elements. To make man live and work in space is also a key objective.

As a matter of fact, most of the science we plan to do onboard the Space Station could be done without the Space Station, except for Life Sciences, which are obviously linked to the presence of man in space. We can do Astronomy, Earth Observation, Technology Experiments, Material Sciences, Fluid Sciences, without the Space Station and WE DO.
However, we shall use, and extensively use, the Space Station because, first, it is there, but not only because it is there. Compared to other means to do science in space, and especially regular satellites, the Space Station has key features that make it a unique tool for science.

1. The Station permits us to avoid the transport through the atmosphere of all resources necessary to make an experiment, each time you wish to make an experiment. The resources stay in orbit and you can limit the transport to just instruments, which is a big advantage when you know that, for example, Spacelab is 13 tons for 3 tons of instruments. The key is to carry less through the atmosphere.

2. The Station has large utilisation resources, at least one order of magnitude above those of a regular satellite - 30 kw, tenth of square metres, hundreds of cubic metres.

3. The Station is permanently available with an access every two to three months, which means that you can change, you can repair, and you can introduce new technology as soon as they are available.

4. The Station is manned, which can be very useful, even if not mandatory. Therefore, the Space Station is a unique tool for scientific utilisation.

The Second Aspect I would like to address is the capabilities which are offered by the Columbus elements. These capabilities are twofold:

- Accommodation capabilities, which mean the number and type of instruments you can accommodate and operate.
- Environmental capabilities, i.e. the microgravity environment for instance, which must satisfy the requirements of experimenters and which could be improved by the development of Microgravity Isolation Mounts.

As for the accommodation capabilities, I would like to comment on two key words:

- multidiscipline, which means that we have to satisfy the requirements of a wide range of users;
- cooperation, which means that we have to take the best benefit of the overall capabilities and resources which are available, i.e. avoiding duplication between the partners.

About the multidiscipline aspect, we consider that it would be a mistake to limit the users to a few categories, considering the 30 years of utilisation in front of us. Five years ago, the favourite users were among the Material Sciences type of users; today the favourite users are with Human Physiology because of space exploration; perhaps five years from now they will be recruited in the biology field, and I trust the scientists to have dynamism enough for proposing completely new ideas on how to use space environment 20 years from now. We have to, therefore, be prepared to face this evolution, and our plans are balancing the utilisation of Columbus among all present user communities.

I shall come back to cooperation later on and let me show you now some material on existing ground facilities, available to prepare the utilisation of Columbus. The Columbus Attached Laboratory full size mock-up includes:

- the real interfaces between the Laboratory system and the payload racks;
- breadboards of typical payload and of the General Purpose Workbench;
- a Telescience testbed simulating the interactive payload operations;
– a Crew Work Station testbed evaluating all technologies able to enhance the role of the astronauts;
– an Automation and Robotics testbed evaluating the capabilities of a multi-purpose robot.

In addition to these ground facilities, extensive utilisation of underwater tests and parabolic flights complete the preparation of Columbus utilisation on ground.

I would like to conclude my presentation with the international aspect: The Space Station is an international venture; we are partners with rights and duties. These rights and duties are clearly defined in the Space Station agreements, the IGA and MOUs. But we have to go beyond these papers and to practise this cooperation, and this is the reason why the preparation of the utilisation of the Space Station must be truly international at both levels, user and agency levels, utilisation and operational levels.

To practise cooperation is the best way to realise that cooperation does not exclude competition and that the combination of cooperation and competition is very fruitful. We know that in Europe, where 13 countries are cooperating through the European Space Agency.

This cooperation is already under way:
1. With NASA, thanks to the IML flights and a cooperative agreement on the EURECA reflights.
2. With all the Space Station partners in order to ensure common interfaces for the users and, in order to share the common equipment on board.

This cooperation does not exclude any partner and, therefore, I am confident that the Space Station will offer a new era of space activities, and just to show you what is true cooperation, let me show you the first advertisement I have discovered for Columbus in a US newspaper...
SPACE LIFE SCIENCES PERSPECTIVES FOR SPACE STATION FREEDOM

Presented by Laurence R. Young, Sc.D.
Massachusetts Institute of Technology and
NASA Johnson Space Center

ABSTRACT

It is now generally acknowledged that the life science discipline will be the primary beneficiary of Space Station Freedom. The unique facility will permit advances in understanding the consequences of long duration exposure to weightlessness and evaluation of the effectiveness of countermeasures. It will also provide an unprecedented opportunity for basic gravitational biology, on plants and animals as well as human subjects. The major advantages of SSF are the long duration exposure and the availability of sufficient crew to serve as subjects and operators.

In order to fully benefit from the SSF, life sciences will need both sufficient crew time and communication abilities. Unlike many physical science experiments, the life science investigations are largely exploratory, and frequently bring unexpected results and opportunities for study of newly discovered phenomena. They are typically crew-time intensive, and require a high degree of specialized training to be able to react in real time to various unexpected problems or potentially exciting findings. Because of the long duration tours and the large number of experiments, it will be more difficult than with Spacelab to maintain astronaut proficiency on all experiments. This places more of a burden on adequate communication and data links to the ground, and suggests the use of AI expert system technology to assist in astronaut management of the experiment. Typical life science experiments, including those flown on Spacelab Life Sciences I, will be described from the point of view of the demands on the astronaut. A new expert system, "PI in a Box," will be introduced for SLS-2, and its applicability to other SSF experiments discussed.
WHY IS SSF VITAL TO SPACE LIFE SCIENCES?

LONG DURATION EXPOSURES

COMPARABLE TO MARS EXPLORATION

ANIMALS AND PLANTS AS WELL AS HUMANS

MULTIPLE GENERATIONS OF PLANTS AND ANIMALS
SSF UTILIZATION

WHAT DOES SSF OFFER FOR LIFE SCIENCES?

CREW TIME:
- SUFFICIENT NUMBER OF SUBJECTS
- SPECIALIZED EXPERIMENTERS
- FLEXIBILITY TO REPLAN STUDIES

MIT Man Vehicle Laboratory

SSF UTILIZATION

FACILITY REQUIREMENTS FROM LIFE SCIENCES

TWO WAY COMMUNICATION AND DATA LINKS
EVENTUAL USE OF UPLINK VIDEO

SAMPLE RETURN CAPABILITY
ON BOARD ANALYSIS
BIOISOLATION
NORMAL ATMOSPHERIC CONDITIONS

MIT Man Vehicle Laboratory
SSF UTILIZATION

MAJOR ON-BOARD EQUIPMENT

BIOISOLATION:
GLOVE BOX TO PROTECT CREW AND SAMPLES

ANIMAL AND PLANT HOLDING FACILITIES

CENTRIFUGE:
PROVIDE 1-G CONTROLS
MAINTAIN 1-G SAMPLES UNITL NEEDED
PERMIT STUDIES IN THE 0-1 G RANGE

HEALTH MAINTENANCE FACILITY

SSF UTILIZATION

SPECIALIZED ON-BOARD EQUIPMENT

LINEAR AND ANGULAR ACCELERATORS

IMAGING DEVICE

LOWER BODY NEGATIVE PRESSURE DEVICE
HUMAN-ORIENTED RESEARCH

ISSUES RELATED TO ADAPTATION TO 0-G

CARDIOVASCULAR DECONDITIONING
PULMONARY FUNCTION ALTERATION
MUSCLE LOSS AND CHANGE OF FIBER TYPES
BONE LOSS AND CHANGE IN CALCIUM BALANCE
PLASMA AND RED BLOOD CELL LOSS
RENAL/ENDOCRINE SYSTEM
IMMUNE SYSTEM
SPACE MOTION SICKNES AND NEUROVESTIBULAR ADAPTATION

PLANT AND ANIMAL EXPERIMENTS

COVER ALL BRANCHES OF PHYSIOLOGY
CURRENT ANIMAL SPECIES: RATS, MONKEYS, FISH
REQUIRE SOME SPECIALIZED CREW SKILLS
RECENT LIFE SCIENCES EXPERIENCE

SPACELAB LIFE SCIENCES 1 (JUNE '92)
FIRST ALL LIFE SCIENCES MISSION
TWENTY INVESTIGATIONS/ SIX BODY SYSTEMS
HUMANS, RATS AND JELLYFISH STUDIED
SUCCESS DEPENDED ON CREW SKILLS

SPACELAB LIFE SCIENCES 2 SCHEDULED FOR 1993

SPECIAL PROBLEM RAISED BY SSF FOR LIFE SCIENCE STUDIES

LONG DURATION TOURS
MULTIPLE DISCIPLINES AND EXPERIMENTS
FLEXIBILITY TO ADJUST PROTOCOLS AND TIMES

BUT

THE CREW NEEDS TIMELY REMOTE COACHING, AND GUIDANCE DURING CONDUCT OF THE EXPERIMENTS

HIGH B/W COMMUNICATION TO PI'S IS AN APPROACH ON-BOARD EXPERTS SYSTEMS ARE ALTERNATIVES
RESEARCH EXPERIENCES ON MATERIALS SCIENCE IN SPACE
ABOARD SALYUT AND MIR

Presented by Liya L. Regel
International Center for Gravity Materials Science and Applications
Clarkson University

ABSTRACT

From 1980 through 1991 approximately 500 materials processing experiments were performed aboard the space stations Salyut 6, Salyut 7 and Mir. This includes work on catalysts, polymers, metals and alloys, optical materials, superconductors, electronic crystals, thin film semiconductors, superionic crystals, ceramics, and protein crystals. Often the resulting materials were surprisingly superior to those prepared on earth. The Soviets were the first to fabricate a laser (CdS) from a crystal grown in space, the first to grow a heterostructure in space, the first superionic crystal in space, the first crystals of CdTe and its alloys, the first zeolite crystals, the first protein crystals, the first chromium disilicide glass, etc. The results were used to optimize terrestrial materials processing operations in Soviet industry.

The characteristics of these three space stations are reviewed, along with the advantages of a space station for materials research, and the problems encountered by the materials scientists who used them. For example, the stations and the materials processing equipment were designed without significant input from the scientific community that would be using them.

It is pointed out that successful results have been achieved also by materials processing at high gravity in large centrifuges. This research is also continuing around the world, including at Clarkson University. It is recommended that experiments be conducted in centrifuges in space, in order to investigate the acceleration regime between earth’s gravity and the microgravity achieved in orbiting space stations. One cannot expect to understand the influence of gravity on materials processing from only two data points, earth’s gravity and microgravity. One must also understand the influence of fluctuations in acceleration on board space stations, the so-called “g-jitter.”

International workshops on high gravity materials processing and jitter are being held at Clarkson in June 1993.
Research Experiences on Materials Science in Space aboard Salyut and Mir

Liya Regel

International Center for Gravity Materials Science & Applications
Clarkson University
"We have labelled civilizations by the main materials which they have used:

The Stone Age,

The Bronze Age,

The Iron Age...

a civilization is both developed and limited by the materials at its disposal. Today, man lives on the boundary between

the Iron Age and the New Material Age."

- Dr. George P. Thomson,
  Nobel Laureate in Physics

**Materials Processing Areas**

- Catalysts
- Polymers
- Metals and Alloys
- Non-Linear Optical Materials
- Superconductors
- Electronic Crystals
- Thin Film Semiconductors
- Ceramics
- Protein crystals
Some Consequences of "Microgravity" Environment

- Greatly reduced buoyancy-driven convection.
- Greatly reduced sedimentation of second phase.
- Greatly reduced hydrostatic pressure.
- Easier containerless processing.
- Surface phenomena more important.

Why Research on Materials Processing in Space?

- Learn more about influence of these phenomena.
- Improve processing on earth.
- Perhaps learn consequence of improved materials.
- Helpful in assembling space stations.
- Maybe manufacturing in space, someday.
CHARACTERISTICS OF MIR

Inclination of orbit: 51.6°
Height of orbit: 300-400 km
Accuracy of orientation:
   Usual - < 1.5
   Precise - < 15 minutes

Total mass of complex: >130,000 kg
Volume pressurized: 400 m
Length of basic block:
   Kvant + 2 spacecraft: 32.9 m
Maximum number of modules: 5
Number of Soyuz that can dock: 0,1,2
Number of Progress that can dock: 0,1

Number of occupants:
   Long term - 2,3
   Short term - 2,3
Kristall technological module with Buran docking port

Soyuz TM9 spacecraft

Mir space station core assembly

Open ports on Mir for additional modules (two)

Kvant astrophysics module

Cosmonauts using space bike (left) and improved spacesuit (right)

Proposal preparation

Discussion
Foreign Investigators

Soviet Investigators

Intercosmos

Academy of Science

Formal proposals for flight experiments

Glavcosmos

Industry

Government Commission

Space Station
Examples of Hardware in Krystal Module

- Gallar  Tube furnace for 33 mm diameter ampoules, maximum temperature 1300 °C, 1 kw.
- Crater  Tube furnace for 56 mm diameter ampoules, maximum temperature 1250 °C, 2 kw.
- Splav   Gradient furnace 20 mm diameter ampoules, 500 to 1050°C, maximum gradient 130K/cm.
- Optizone Mirror furnace for floating zone melting of 10 mm diameter silicon up to 150 mm long, 300 to 2100 °C, up to 1.6 kw.

Characteristics of Typical Scientific Module: Kristall

- Mass of Module  20,600 kg
- Length of module 12.5 m
- Mass of payload  5,000 kg
- Transport vehicle Proton or Energy
Advantages of Crystal Growth in Mir and Salyut

- Could perform long duration experiments.
- Cosmonauts available to repair equipment and modify experiments.
- A lot of space for equipment, including materials characterization equipment and general purpose apparatus.
Some Crystal Growth Results from Mir and Salyut

- First to fabricate laser from crystal (CdS) grown in space.
- First semiconductor heterostructure grown in space.
- First crystals of CdTe, HgCdTe, ZnCdTe, and MnCdTe.
- First superionic crystal grown in space.
- Large monodispersed polymer latex spheres.
- First zeolite crystals, several times larger than on earth.

- First protein crystals; insulin, pro-insulin, glucogen, tymozine, antitrypsin, interferon.
- First chromium disilicide glass.
- First crystallization by rapid mixing of two solutions, to grow hydroxyapatite and calcium sulfate (gypsum).
- Results helped to optimize terrestrial crystal growth...
Problems Encountered in Mir and Salyut

- Designed without input from user community, resulting in:
  - Limited power for experimental equipment.
  - Limited periods when power available for experiments.
  - Mass restrictions for equipment.
  - Limited time for experiments.
  - Equipment located far from center of mass of station.
  - Limited air-to-ground communications and data transmission.
- No accelerometer data to Investigators.
- Lengthy delays in return of samples and data to Investigators.

- Too many scientific disciplines for cosmonauts to master.
- Insufficient training on flight apparatus before launch.
- Excessive paperwork for Investigators.
- Replication of experiments rarely possible.
- No support for thorough analysis of flight samples and results.
- Criteria for selection of flight experiments never revealed.
**Phenomena in a centrifuge**

- Sedimentation
- Increased pressure
- Increased buoyancy convection
- Coriolis forces
- Acceleration gradients
**Materials Processing Results**

- **Very high g:**
  - Solution growth
  - Eutectic solidification
  - Movement of solvent inclusions

- **Moderate g with unstable gradient**

- **Moderate g with “stable” gradient**
  - Single phase solidification
  - Eutectic solidification

- **Vapor transport at moderate g**

**Implications of Fluid Flow Experiment to Crystal Growth**

- Space Centrifuge Fluid Flow Experiment will increase the understanding of the controlling forces influencing crystal growth of any material in a wide range of g levels.

- Crystal growth in a centrifuge offers a unique environment in which the fluid flow magnitude and flow pattern are controllable, which in turn effects the concentration field.
Why Materials Processing Experiments in a Centrifuge in Space Station Freedom?

- To obtain data points between $10^{-6}$ g and 1 g; necessary to understand influence of g.
- To explain ground based results from centrifuge without complications of earth's gravity.

First International Workshop on g-jitter

Clarkson University, June 13-18, 1993

- What is g-jitter and how does it arise?
- How can it be predicted?
- How can it be measured?
- How can it be reduced and controlled?
- What does it do to fluids?
- How does it influence materials processing?
- How does it influence combustion?
- How does it influence biological processes?
- What R&D needs to be done?
One of the most pervasive myths of space materials science is that "nothing is known for sure." This adage projects a disarming modesty. Even scientists have been known to fall into the arms of this myth in order to avoid the appearance of dogmatism and arrogance.
Space, Space, Space Science . . . what a wonderful, powerful sounding word! It instantly induces an atmosphere of pure rationality. It rings loudly a symphony of universal knowledge and understanding. It forcefully projects an aura of all encompassing order and of control.

In terms of quantity and in terms of analytic inference, it seems to me that space science and sports are very much parallel at the level of public concern. A lot of complexity, a lot of tactics, a lot of numbers, and a lot of perhaps poorly understood probabilistic judgements are present.
ALL ABOARD!
First, I want to thank John Bartoe, Jack Lee, Jed Pearson, Arnie Aldrich, and the rest of the NASA team for sponsoring this conference, and all of you for attending, including our international partners from ESA, Canada, and Japan. The more you learn about the possibilities for Space Station Freedom, the more excited you get.

One of the challenges we face as a society — certainly in this period of slow economic growth — is to focus not on the present, but on the future. I believe one of the reasons we’re having problems with our economy is that we’re not investing in our future to the degree we should.

When I was born in 1940, there were about two billion people on Earth. Today, that’s more than doubled to 5.5 billion. And when I’m 100 years old, there’ll be almost 10 billion. The people alive during my life have consumed more of the world’s resources than all those living in prior generations of human history. We’ve already used more than we deserve, and now we’re stealing from the future to buy the creature comforts of today.

We see it in government, where we have big deficits year after year. We see it in the corporate world, where the focus is on short-term profits, not long-term investment. Last year, the aerospace companies that invested the least in research and development saw their stock prices go up the most. While the rest of the world gears up for the economic competition of the post-Cold War era, America is chowing down on its seed corn to feed its belly today.

NASA scientist Rick Chappell, who works at Marshall, recently had an experience that illustrates this quite clearly. As he was jogging through the wildlife refuge that surrounds the launch pads at Cape Canaveral, he noticed an armadillo by the trail. Later, he looked up and saw an eagle.

He wrote later on, “I was struck by the contrast of their different approaches to life. Where the armadillo never looks up — concentrating only on its next meal, and oblivious to the world around it — the eagle soars quietly and majestically. It is not rooting around on the ground, but is striving for the high ground — seeking a vantage point from where to see the horizon and beyond.”

America’s first spacecraft that landed on the Moon wasn’t called the armadillo; it was the Eagle — the symbol of America. This nation didn’t become the greatest in the world by keeping its eyes on the ground. We are about broad visions, about looking over the horizon to see the future, and then blazing the trail for others to follow.

Technology is the fuel in our economic furnace. Technology creates growth. It creates whole new industries and new jobs — high paying, high quality jobs that add value to our economy.

NASA’s research and development of advanced technology reaches out into the future to bring back opportunities to the world of today. Between 1979 and 1986, the new products generated from NASA science and engineering created over 350,000 new jobs. And believe me, this is a very conservative estimate, because once NASA invents something and makes it available to industry, we lose track of many byproducts that build on our pioneering work.
NASA has been driving technology forward ever since it was created. Apollo brought us untold bounty—especially in medical technology. Pacemakers, CAT scans, magnetic resonance imaging, intensive care monitoring equipment—all got their start because of research NASA needed to go into space. Mission Control's computer networks and software are the great grandfathers of what runs America's telephone system, banking and credit card networks, and airline computer networks.

But we can't keep living off Apollo's bounty. Currently, the hair of a scientist can turn gray waiting to get their first experiment on the shuttle, let alone the necessary follow-up research. A researcher can't make much progress doing one experiment every few years of so. We can't keep attracting good people to do space science if the research they need for their Ph.D. takes decades to complete.

The House of Representatives took a giant leap in the right direction last week when they voted to continue building Space Station Freedom. As I listened to the debate in the House Chamber and watched the vote tally grow, I was proud that in these difficult economic times, Congress saw the wisdom in investing in our future. It was not just a victory for NASA, but a victory for America and its international partners, who desperately needs the research and technology that will come from a permanent facility in space.

Space Station Freedom will revolutionize our way of life in the 21st century the same way the Apollo program did in the 20th century.

A permanent space station will be the place where we become a true space-faring nation—the place where we learn how to live and work in space. And it will be an example of how nations can unite and work together on projects of peace. All of our plans to build an outpost on the Moon and explore Mars depend on using Space Station Freedom to conduct the necessary life science research to protect astronaut's health from the effects of long duration space travel.

While these studies are going on, the space station will have dual use lab equipment where scientists can systematically study how living organisms and other materials behave without gravity. Essentially, the space station should be thought of as an international research center in orbit. Researchers from universities and the private sector, such as pharmaceutical companies, and our international partners will be able to share facilities on Freedom to facilitate basic research in materials processing biotechnology, and life sciences.

Biotechnology, for instance, is expected to be the big business of the 90s, going from $4 billion a year currently to $50 billion by the end of the decade—revolutionizing everything from agriculture to pollution control to health care. The commercial possibilities of biotechnology research in microgravity are mind-boggling. Product improvements developed from this research can fuel the furnace of our economy, creating new jobs and saving lives with new drugs and medical knowledge.

The stunning success of the U.S. Microgravity Lab on the last shuttle flight showed the vast potential of Space Station Freedom. On that flight was Astronaut Larry DeLucas of the University of Alabama at Birmingham, who's an expert in growing protein crystals, which are key to developing new drugs. The protein crystals grown on that flight were some of the largest and best-formed ever. Drug companies and other researchers had attempted to grow some of them on Earth to no avail. One drug company said they accomplished in two weeks an experiment that would have taken two years on the ground.

Yet despite this successful shuttle mission, Dr. DeLucas reached two conclusions: 1) that even a 14-day shuttle flight was not enough time for some of the experiments, and 2) a lab is needed in which scientists can interact and manipulate the experiments on a day-to-day basis.
That’s why we need Space Station Freedom. The tidal wave of research that’s waiting to be flown in space is what can let us live longer lives, in a cleaner environment, with a higher standard of living.

Clearly investing in the future is worth it, but at what cost? Many people don’t realize that NASA receives only 1% of the federal budget — literally two cents a day for every American citizen. When you consider the enormous return on investment a space station will yield, Americans will get far more than their two cents’ worth. For that small amount, the dividends we pay are enormous.

Life on Earth is better because of the lives we’ve sent into space. Thank goodness we have a president who understands how important space is to the strength, and competitiveness, and future economic growth of America. George Bush and Dan Quayle support a robust civil space program because they’ve seen how science and technology drives this nation forward. Our international partners know this as well, which is exactly why they’ve joined us.

Every time we have gone to the frontier, we’ve brought back more than we could ever imagine. Space is no longer just an experiment or a symbol. It’s no longer a “luxury,” the way automobiles and air travel were once viewed. Space is an essential part of our future in medicine, science, and technology.

We have to get bold again. We have to take risks and make investments so our children will have a better future. By reaching for the stars, we bring inspiration, hope, and opportunity back to Earth.

The “armadillos” of the world cannot defeat those of us who choose to be eagles. By flying higher, and seeing farther, we will use our vision to lead the way for the benefit of all humanity.

Let me leave you with a vision of what the space station could mean. It’s early in the next century, and a woman in Montgomery, Alabama goes to her doctor to receive a hormone shot to prevent osteoporosis. That night, she sees on TV that a young astronaut at Kennedy Space Center just received the same shot to prevent bone loss before blasting off on the long journey to Mars.

That young astronaut grew up in Huntsville, where decades before, her father was a builder of Space Station Freedom, on which the life science research for long-term space flight uncovered the hormone that prevents osteoporosis. Her father’s work on Space Station Freedom had inspired her to study organic chemistry so that when the time came, she’d be qualified to go search for signs of ancient life on Mars.

Space Station Freedom isn’t just a job, or a chance to make money. It’s a mission to move the human species into breaking the chains of gravity and becoming a multi-planetary society. Pursuing a mission of this monumental importance will lift civilization on Earth to new heights of health, wealth, and knowledge.

The exploration of space is the most inspirational adventure of all time. Our work offers hope that our children’s world will be a better place than our own. Join me as we make this vision a reality.
LIFE SCIENCES UTILIZATION OF SPACE STATION FREEDOM

Presented by Lawrence P. Chambers
Office of Space Science and Applications
NASA Headquarters

ABSTRACT

Space Station Freedom will provide the United States’ first permanently manned laboratory in space. It will allow, for the first time, long term systematic life sciences investigations in microgravity. This presentation provides a top-level overview of the planned utilization of Space Station Freedom by NASA’s Life Sciences Division. The historical drivers for conducting life sciences research on a permanently manned laboratory in space as well as the advantages that a space station platform provides for life sciences research are discussed. This background information leads into a description of NASA’s strategy for having a fully operational International Life Sciences Research Facility by the year 2000. Achieving this capability requires the development of the five discipline-focused “common core” facilities. Once developed, these facilities will be brought to the space station during the Man-Tended Capability phase, checked out and brought into operation. Their delivery must be integrated with the Space Station Freedom manifest. At the beginning of Permanent Manned Capability, the infrastructure is expected to be completed and the Life Sciences Division’s SSF Program will become fully operational. A brief facility description, anticipated launch date and a focused objective is provided for each of the life sciences facilities, including the Biomedical Monitoring and Countermeasures (BMAC) Facility, Gravitational Biology Facility (GBF), Gas-Grain Simulation Facility (GGSF), Centrifuge Facility (CF), and Controlled Ecological Life Support System (CELSS) Test Facility. In addition, hardware developed by other NASA organizations and the SSF International Partners for an International Life Sciences Research Facility is also discussed.
Space Life Sciences Goals and Objectives

- Ensure the health, safety, and productivity of humans in space
- Acquire fundamental scientific knowledge concerning space biological sciences
- Expand our understanding of life in the Universe
- Develop an understanding of the role of gravity on living systems
- Provide for the health and productivity of humans in space
- Promote the application of life sciences research to improve the quality of life on Earth
Historical Drivers for Space Life Sciences Research on Space Station Freedom

1958  NASA Charter called for the expansion of human knowledge of phenomena in the atmosphere and space

1987  Goldberg Report - Identified a complementary strategy combining basic life sciences and clinical research on Space Shuttle and early SSF

1988  Robbins Report - Endorsed the capability of basic research on the Space Station using plants, animals, and humans

1990  Augustine Report - Identified life sciences research as a major reason for building the Space Station

1992  NASA Advisory Council - Developed list of science questions to be answered by life sciences research on Space Station to enable a mission to the Moon or Mars
Why Space Station for Biological Research?

- First permanently manned laboratory in space
- Allows long-term, systematic investigations under controlled conditions
  - Study growth and maturation over time
  - Examine living specimens through multiple generations (seed to seed to seed)
  - Replication based on experimental results
- Statistical Analysis
  - Adequate sample size
  - Appropriate control populations
  - Verification through replication

Life Sciences Space Station Freedom Strategy

- Life Sciences Space Station Freedom Program will be performed using a suite of discipline-focused "common core" facilities
  - Five common core facilities being developed by NASA Life Sciences
  - Generic hardware will be used for numerous applications
  - Will be able to support the wide range of life sciences disciplines
  - Integral part of International Life Sciences Research Facility
- Use Man-Tended Capability (MTC) to develop research infrastructure to establish an International Life Sciences Research Facility. Major objectives during the MTC Phase are:
  - Bring facilities to orbit and install in pressurized volume
  - Verify and check-out hardware for proper operation
  - Perform science experiments (i.e. Spacelab class) that can be adequately performed in an MTC environment
Life Sciences Space Station Freedom Strategy
(Continued)

- Once Permanent Manned Capability achieved (year 2000), life sciences capabilities will be fully operational
  - Can devote in-depth study to each discipline for extended periods of time (nominally 6 months)
  - Hardware items (including Experiment Unique Equipment) can be changed out to match particular discipline focus
POTENTIAL CENTRIFUGE LOCATION ON SPACE STATION FREEDOM

Permanently Manned Capability
<table>
<thead>
<tr>
<th>Life Sciences Space Station Freedom Research Facilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Biomedical Monitoring and Countermeasures Facility</td>
</tr>
<tr>
<td>— 4 rack facility</td>
</tr>
<tr>
<td>— 1st launch—1997</td>
</tr>
<tr>
<td>— Objective is to understand how to maintain crew health and performance for missions of 16 days and longer in a manner that minimally impacts mission operations and resources</td>
</tr>
<tr>
<td>• Gravitational Biology Facility</td>
</tr>
<tr>
<td>— 2 rack facility</td>
</tr>
<tr>
<td>— 1st launch — 1998</td>
</tr>
<tr>
<td>— Objective is to provide the generic laboratory equipment needed to conduct basic life sciences research in cell biology, developmental biology, and plant biology</td>
</tr>
<tr>
<td>• Centrifuge Facility</td>
</tr>
<tr>
<td>— 2.5 meter centrifuge plus two habitat racks</td>
</tr>
<tr>
<td>— 1st launch — late 1999</td>
</tr>
<tr>
<td>— Objective is to provide a suite of equipment to allow controlled studies on the influence of gravity on biological systems</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Life Sciences Space Station Freedom Research Facilities (Continued)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Gas Grain Simulation Facility</td>
</tr>
<tr>
<td>— 1 rack facility</td>
</tr>
<tr>
<td>— 1st launch — 1998</td>
</tr>
<tr>
<td>— Objective is to simulate and study fundamental chemical and physical processes of submicron to millimeter sized particles in microgravity to improve understanding of the formative processes of the universe</td>
</tr>
<tr>
<td>• Controlled Ecological Life Support System (CELSS) Test Facility</td>
</tr>
<tr>
<td>— 2 rack facility</td>
</tr>
<tr>
<td>— Launch — 1999</td>
</tr>
<tr>
<td>— Objective is to study crop growth and productivity in microgravity under a broad range of environmental conditions</td>
</tr>
</tbody>
</table>
Other Contributions to Life Sciences Research

Other facilities not funded by the Life Sciences Division will be utilized to achieve life sciences research objectives:

- Laboratory Support Equipment/General Laboratory Support Facilities
  - Funded by Office of Space Flight/Office of Space Science and Applications
  - Will be shared by all SSF users (life sciences, materials sciences, commercial applications, etc.)

- International Partner Life Sciences Facilities
  - International Partners (ESA, NASDA, CSA) are planning to provide life sciences research hardware for SSF
  - NASA Life Sciences will coordinate closely with our International Partners so that an integrated International Life Sciences Research Facility is developed for SSF
  -Eliminates duplicate hardware
  -Provides most efficient use of limited resources

Rack Totals For Life Sciences Facilities

<table>
<thead>
<tr>
<th>Biomedical Monitoring and Countermeasures</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravitational Biology Facility</td>
<td>2</td>
</tr>
<tr>
<td>Gas-Grain Simulation Facility</td>
<td>1</td>
</tr>
<tr>
<td>Centrifuge Facility</td>
<td>2 + Centrifuge System</td>
</tr>
<tr>
<td>CELSS Test Facility</td>
<td>2</td>
</tr>
<tr>
<td>Total Racks:</td>
<td>11 + Centrifuge System</td>
</tr>
<tr>
<td>Summary</td>
<td></td>
</tr>
<tr>
<td>---------------------------------</td>
<td></td>
</tr>
<tr>
<td>• LIFE SCIENCES LOOKS FORWARD TO SPACE STATION FREEDOM ERA</td>
<td></td>
</tr>
<tr>
<td>• First permanently manned laboratory in space</td>
<td></td>
</tr>
<tr>
<td>• Allows systematic, long-term life sciences investigations under controlled conditions</td>
<td></td>
</tr>
<tr>
<td>• Permits satisfactory statistical analysis of in-flight results</td>
<td></td>
</tr>
<tr>
<td>• Information obtained from life sciences research on Space Station Freedom will be utilized for lunar and Mars missions</td>
<td></td>
</tr>
</tbody>
</table>
LIFE SCIENCES RECRUITMENT OBJECTIVES

Presented by Dr. J. Richard Keefe
Office of Space Sciences and Applications
NASA Headquarters

ABSTRACT

The goals of the Life Sciences Division of the Office of Space Sciences and Application are to ensure the health, well being and productivity of humans in space and to acquire fundamental scientific knowledge in space life sciences. With these goals in mind, Space Station Freedom represents substantial opportunities and significant challenges to the Life Sciences Division. For the first time it will be possible to replicate experimental data from a variety of simultaneously exposed species with appropriate controls and real-time analytical capabilities over extended periods of time. At the same time, a system for monitoring and ameliorating the physiological adaptations that occur in humans subjected to extended space flight must be evolved to provide the continuing operational support to the SSF crew. To meet its goals, and take advantage of the opportunities and overcome the challenges presented by Space Station Freedom, the Life Sciences Division is developing a suite of discipline-focused sequence. The research phase of the Life Sciences Space Station Freedom Program will commence with the utilization flights following the deployment of the U.S. laboratory module and achievement of Man Tended Capability. Investigators that want the Life Sciences Division to sponsor their experiment on SSF can do so in one of three ways: submitting a proposal in response to a NASA Research Announcement (NRA), submitting a proposal in response to an Announcement of Opportunity (AO), or submitting an unsolicited proposal. The scientific merit of all proposals will be evaluated by peer review panels. Proposals will also be evaluated based on relevance to NASA’s missions and on the results of an Engineering and Cost Analyses. The Life Sciences Division expects that the majority of its funding opportunities will be announced through NRAs. It is anticipated that the first NRA will be released approximately three years before first element launch (currently scheduled for late 1995). Subsequent NRAs will be released on a rotating two year cycle.
LIFE SCIENCES RECRUITMENT OBJECTIVES

Dr. J. Richard Keefe
Program Scientist, Life Sciences Division
Space Station Freedom Program

SPACE LIFE SCIENCES GOALS AND OBJECTIVES

- Ensure the health, safety, and productivity of humans in space
- Acquire fundamental scientific knowledge concerning biological sciences
- Expand our understanding of life in the Universe
- Develop an understanding of the role of gravity on living systems
- Provide for the health and productivity of humans in space
- Promote the application of life sciences research to improve the quality of life on Earth
LIFE SCIENCES SPACE RESEARCH STRATEGY

Phase I
Mercury, Gemini, Apollo (1960's)

Objectives
• Human Survival
• Adequate Human Performance for Lunar Trip

Methodology
• Pre-/Post-flight Human Studies
• Highly Limited Inflight Studies

Phase II
Skylab (1970's)

Objectives
• Human Adaptation for 2-3 Months
• Biomedical Research Focus

Methodology
• Extensive Noninvasive Biomedical Studies
• Frequent Inflight Collection of Blood and Urine
• First Provocative Testing in Space

Phase III
Spacelab, Middecks, COSMOS (1980's, Early 1990's)

Objectives
• Focused Second Generation Biomedical Studies
• Initial Testing of Animals as Human Surrogates
• Initiation of Research in Basic Biology

Methodology
• Limited Invasive Studies on Humans
• Invasive Animal Studies
• Sophisticated Laboratory Equipment
• Plant and Cell Biology Facilities

Phase IV

Plant and Cell Biology Facilities
Phase IV
Late Spacelab, MIR, Early Space Station Freedom (Mid-Late 1990's)

Objectives
- Third Generation Biomedical Studies (Countermeasures Emphasis)
- Development of Animal Models
- Develop Foundations for Exploration
- Fundamental Studies in Basic Biology

Methodology
- Integrated International Laboratories
- Comprehensive Laboratory Research Facilities
- Carefully Controlled Human, Animal, and Plant Studies
- Replications as Required

IMPETUS FOR SPACE STATION FREEDOM

"...back to the Moon, back to the future. And this time, back to stay. And...a journey into tomorrow...a manned mission to Mars." President George Bush, 1989.

"...the Space Station is deemed essential as a life sciences laboratory, for there is simply no Earth-bound substitute. The Space Station is a critical next step if the U.S. is to have a manned space program in the future." Report of the Advisory Committee on the Future of the U.S. Space Program, 1990.

"[Space Station] Freedom will provide the means to acquire basic knowledge on mechanisms of gravity perception while paving the way for extended-duration exploration missions with humans." Space Life Sciences Strategic Plan, 1992.
RECENT RECOMMENDATIONS
TO THE LIFE SCIENCES

- Life Beyond the Earth's Environment: The Biology of Living Organisms in Space. NRC Space Science Board. Neal S. Bricker, Chairman. 1979
  - Focused on science priorities for Spacelab missions

- A Strategy for Space Biology and Medical Science: for the 1980s and 1990s. NRC Space Science Board. Jay M. Goldberg, Chairman. 1987
  - Focused on developing priorities for late STS and early space station program

  - Focused programmatic requirements for Space Station Freedom

- Life Sciences Discipline Working Group Science Plans. 1991
  - Focused on discipline specific science
  - Developed prioritized list of critical questions within each discipline

  - Focused on meeting requirements for Moon/Mars missions
  - Developed prioritized list of science questions across disciplines

SPACE LIFE SCIENCES CUSTOMERS

1. MISSION IMPLEMENTORS
   - Requirement: Capability for human exploration of space
   - LSD Product: Deliverables identified by AMAC strategy

2. SCIENCE COMMUNITY
   - Requirement: Access to space for conduct of scientific research
   - LSD Product: Support of science described in discipline plans

3. PUBLIC
   - Enhance the quality of life on Earth
   - Stimulate the imagination
   - Motivate science and engineering education
### CATEGORIES FOR LIFE SCIENCES DISCIPLINES

<table>
<thead>
<tr>
<th>Category</th>
<th>Subcategories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human Physiology and Performance</td>
<td>Behavior, Performance and Human Factors</td>
</tr>
<tr>
<td></td>
<td>Regulatory Physiology</td>
</tr>
<tr>
<td></td>
<td>Cardiopulmonary</td>
</tr>
<tr>
<td></td>
<td>Musculoskeletal</td>
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<td></td>
<td>Neuroscience</td>
</tr>
<tr>
<td>Life Support</td>
<td>Environmental Health</td>
</tr>
<tr>
<td></td>
<td>Radiation Health</td>
</tr>
<tr>
<td></td>
<td>Life Support, including CELSS</td>
</tr>
<tr>
<td>Gravitational Biology</td>
<td>Cell and Developmental Biology</td>
</tr>
<tr>
<td></td>
<td>Plant Biology</td>
</tr>
<tr>
<td>Exobiology</td>
<td>Exobiology</td>
</tr>
<tr>
<td></td>
<td>Planetary Protection</td>
</tr>
</tbody>
</table>

### ENABLING LIFE SCIENCES RESEARCH THRUSTS FOR HUMAN EXPLORATION MISSIONS

**Environmental Health and Life Support Systems (EHLSS)**
- Protect from the space environment
  - Vacuum
  - Radiation
  - Absence of atmosphere, food, water

**Countermeasure Systems (CMS)**
- Compensate for the effects caused by the space environment
  - Hypogravity
  - Confined space
  - Limited crew size

**Medical Care Systems (MCS)**
- Provide clinical intervention or treatment
  - Decompression sickness
  - Transfusions
  - Bone fracture
## Definitions of Criticality, Robust and Constrained Programs

<table>
<thead>
<tr>
<th>Category</th>
<th>Criticality 1</th>
<th>Criticality 2</th>
<th>Criticality 3</th>
<th>Criticality 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>EHLSS</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>CMS</td>
<td></td>
<td></td>
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<tr>
<td>MCS</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Enabled Science</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Basic Science</td>
<td></td>
<td></td>
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</tbody>
</table>

**Criticality 1:** Consensus that answer is required for Mars mission (known effect and known problem for mission).*

**Criticality 2:** Answers might be required, science basis to evaluate risk is not adequate.

**Criticality 3:** Required for practical optimization of resources (or countermeasure effectiveness) and minimization of risk.

**Criticality 4:** Important science that is relevant to exploration mission.

* Crewmembers must be able to effectively perform mission tasks in transit vehicles and on planetary surfaces; and must recover, in a reasonable time, upon return to Earth.

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### Life Sciences Research Resources

- **Space Station Freedom**
  - Predominantly manned operations
  - Lengthy exposure to all levels of hypogravity
  - Variable gravity experimental comparisons
  - Replication of experimental procedures
  - Real-time analytical capabilities

- **STS/Spacelab**
  - Manned or man-tended operations
  - Testbed for SSF techniques/equipment
  - 7-16 day missions, evolving to 30-day
  - Earth based analyses of samples/data

- **Unmanned Free Flyers**
  - Unmanned science
  - Earth based analyses of samples/data
  - Variable inclination/orbital environment
  - "Quiet" periods of microgravity available

---

Life Sciences planning matches Science Requirements with the most appropriate Platform.
### METHODS OF FUNDING

#### Unsolicited Proposals

- **Announcement of Opportunity NASA Research Announcement**

#### SOLICITED PROPOSALS

<table>
<thead>
<tr>
<th>Types of investigations</th>
<th>NASA Research Announcements (NRA)</th>
<th>Announcements of Opportunity (AO)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• ground-based research</td>
<td>• flight hardware development</td>
</tr>
<tr>
<td></td>
<td>• flight experiments not requiring</td>
<td>oriented projects</td>
</tr>
<tr>
<td></td>
<td>major hardware development</td>
<td></td>
</tr>
<tr>
<td>Funding mechanism</td>
<td>• usually grants</td>
<td>• usually contracts</td>
</tr>
<tr>
<td>Funding level</td>
<td>• varies, depending on</td>
<td>• varies usually larger than NRA</td>
</tr>
<tr>
<td></td>
<td>requirements/justification</td>
<td>due to complex nature of</td>
</tr>
<tr>
<td></td>
<td></td>
<td>hardware development</td>
</tr>
<tr>
<td>Evaluation process</td>
<td>• peer reviewed science</td>
<td>• peer reviewed science</td>
</tr>
<tr>
<td></td>
<td>• NASA programmatic evaluation</td>
<td>• NASA programmatic evaluation</td>
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<tr>
<td></td>
<td></td>
<td>• more involved &quot;CEM&quot; evaluation</td>
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<tr>
<td></td>
<td></td>
<td>than NRA</td>
</tr>
</tbody>
</table>
UNSOLICITED PROPOSALS

- Investigator initiated
- Mailed directly to appropriate Program Manager
- Evaluated like NRA/AO
- Appropriate for small, low cost experiments utilizing existing hardware/facilities

SOLICITATION OF RESEARCH
ON SPACE STATION FREEDOM

- Primary method of solicitation/funding will be through discipline focused NASA Research Announcements (NRA).
  - Discipline sequence will be determined in consultation with the scientific community and our international partners.
- NRAs will announce submittal dates for established discipline sequences.
- Nominal two year cycle from solicitation to funding.
EXAMPLE DISCIPLINE FOCUSED INCREMENTS

METHODS OF FUNDING

Unsolicited Proposals

Announcement of Opportunity

NASA Research Announcement

Target Funding Range $60 - $100 K per year
PROPOSAL EVALUATION CRITERIA

- Scientific merit - determined by an extramural peer review panel
- Relevance to NASA's mission - determined by NASA
- Engineering, Cost, and Management Review - standardized review performed by NASA. Used to assess costs, development risks, hardware availability, potential incompatibilities, and the technical aspects of implementing the proposed investigation.

TYPES OF FLIGHT OPPORTUNITIES ON SPACE STATION FREEDOM

Utilization of common-core facilities

- Nominal use
  - facilities used as provided, no additional hardware built
  - solicitation to integration/flight cycle = 2 years

- Experiment Unique Equipment required
  - additional hardware or significant modifications to facilities required
  - solicitation to integration/flight cycle > 2 years

- Small and Rapid Response Payloads
  - small experiments
  - integrated tissue sharing protocols
  - integration/flight may be accomplished in 6 months
SUPPORT PROVIDED BY THE NASA GRANT

- Experiment definition, development, and ground based data collection.
- Development of Experiment Unique Equipment (EUE) - if approved.
- Postflight data analysis

OTHER SUPPORT PROVIDED BY NASA

- Experiment Integration
  - Physical
  - Analytical
- Use of common-core facilities and hardware
- Mission operations/logistics
- Inflight data collection
- Data Archive
The Space Station Freedom Program (SSFP) represents the transition within the US Space program from the "heroic" era of space flight (characterized most vividly by the Mercury and Apollo programs) to an epoch characterized by routine access to the space environment. In this new era, the unique characteristics of the microgravity environment will enable new types of research activities, primarily in the life sciences, materials science, and biotechnology fields.

In addition to its role as a "microgravity science laboratory," Space Station Freedom (SSF) constitutes the operational platform on which the knowledge and skills needed to continue our exploration of space will be acquired. In the area of spacecraft operations, these skills include the ability to assemble, operate, and maintain large structures in space. In the area of crew operations, the potentially harmful effects of extended exposure to microgravity must be understood in order to keep the crew mission capable. To achieve this goal, the complex process of physiological deconditioning must be monitored, and countermeasures utilized as needed to keep the individual crew members within acceptable physiological limits.

The countermeasures program under development for the SSF Program is titled the Biomedical Monitoring and Countermeasures (BMAC) program. As implied by the name, this activity has two primary products, a biomedical monitoring element and a countermeasures development effort. The program is a critical path element in the overall SSF Program, and should be considered an essential element of operations on board the space station.

It is readily apparent that the capability to both protect and optimize the health and performance of the human operators onboard SSF will be a critical element in the overall success of the SSFP. Previous experience within the Russian space program has demonstrated that the time required for countermeasures on extended missions can become a monumental operational burden. Therefore, one of the primary objectives of the countermeasures development activity will be to design and implement countermeasures which are significantly more effective than the existing generation. Other primary objectives include the following:

- To set health and human performance standards for all mission phases.
- To determine critical issues that affect performance or return to flight status.
- To develop and implement monitoring systems to follow health and performance status.
- To understand risk, and balance the resource costs of countermeasures vs. the benefit gained.
Program Overview

Don Stewart, M.D.
BMAC Program Manager

A Fact

EITHER SINGLY OR IN COMBINATION, THESE HUMAN RESPONSES ARE DIRECT LIMITATIONS TO MANNED SPACE FLIGHT MISSIONS

- Bone density is reduced
- Muscle strength and mass are reduced
- Neurological changes affect gait, stability, and cardiovascular function on return to a gravity environment
- Would healing appears to be impaired
- Body fluid volume and blood volume, including both plasma volume and red blood cells, are reduced
- Orthostatic intolerance and exercise capacity loss is manifested on re-exposure to gravity
- Space motion sickness is experienced during the first week of space flight by about half of the crewmembers
- Cardiac arrhythmias have been seen during extravehicular activity and other mission phases
- Immunity is impaired after prolonged space flight
- Absorption of medications is impaired
- Hormone blood levels and function are altered
- Interpersonal conflicts, irritability and fatigue are increased on long duration space flight missions
Mission Needs Statement

- NASA plans to continue to fly humans in space
- First, NASA must be sure in so doing that it does not subject humans to a level of risk that is not understood and acknowledged to be appropriate for NASA's overall mission
- Second, NASA must be sure in so doing that human participants are capable of providing the level of activity and performance required to assure mission success

NASA has a need to conduct a continuing program of biomedical monitoring and countermeasure development to assure that space flight involving humans does not contain unknown or unmitigated risks at a level that would harm participating crewmembers or cause mission success to be impacted

BMAC - Biomedical Monitoring and Countermeasures is that program

Background

- Space Medicine as a speciality is in the early stages of discipline development
  - We (including the Russian experience) do not understand the full extent of human risk associated with space flight or the means to mitigate that risk to acceptable levels (more details later in briefing)
- Increasing mission durations (and complexity) carry progressively higher risk levels
- CHeCS (Crew Health Care System) as a stand-alone capability was not intended to accomplish the goals and objectives of BMAC
- BMAC provides the essential medical data base in support of current and future programs (including SEI)
- If human space flight is to successfully extend beyond 16 days, this is a "must do" and not a "could do" program
  - We assume that there will be a continuous progression of the human presence in space
Specific Mission of BMAC

Assure the health, well-being, and performance of humans during space operations through a process of diligent monitoring of human adaptation and performance and application of countermeasures

- Health
  - Maintain crewmembers below a clinical horizon
  - Provide information to the clinical health care program so that clinical and long-term health issues are integrated

- Well-being
  - Assure optimal crew performance by maintaining a positive quality of life
  - Monitoring and countermeasures must be efficiently integrated into the operational environment

- Performance
  - Humans must be able to perform in space and on return to earth according to the requirements of each mission

BMAC Goals

- To understand and maintain crew health and performance on missions 16 days and longer
- To provide systems and procedures which minimize the time required to return to flight status
Agency Goals

- It is NASA's policy when humans travel in space
  - Medical risk is reduced to an acceptable minimum level
  - They are provided medical care and support to enable them to accomplish the goals of the mission
- Recent Presidential directives have provided a major challenge to that policy
  - "establishing a permanent human presence in space"
  - This requires a level of effort and priority above that needed for current short duration flights (16 days or less)
- Advisory groups have been unanimous in their support for a vigorous human life science program
  - Robbins, Augustine, Stafford, AMAC

BMAC Objectives

- To set health and human performance standards for all mission phases
- To determine critical issues that affect performance or return to flight status
- To develop and implement monitoring systems to follow health and performance status
- To develop, implement, and validate countermeasures that mitigate the negative biomedical consequences of mission 16 days and longer
- To understand risk, and balance the resource costs of countermeasures vs. the benefit gained
Typical Programmatic Questions Addressed by BMAC

- What are the optimal biomedical monitoring scenarios and schedules?
- Are there physiological, biochemical, or behavioral changes that limit mission duration?
- Do these changes limit the number of missions an individual can fly?
- How can crew productivity be optimized on flights of increasing duration & mission complexity?
- What countermeasures are needed? When?
- Is there an optimum mission length?
- How can the operational impacts from monitoring & countermeasures application be minimized?
- Are there crew selection criteria related to observed changes that need to be implemented?
- What major program/mission design considerations should be considered during early planning and development?

Primary Deliverables

- Risk levels associated with un-mitigated human adaptation to and operation in the space flight environment
- Evaluation of the impact of these human risks on mission performance and success
- A set of operational countermeasures that reduce unacceptable human risks to acceptable levels
- Biomedical monitoring equipment, procedures, data analysis techniques, and selection criteria that provide individualized risk status during all mission phases
- Human-machine interfaces and habitability requirements
- A set of recommendations for mission planning and operations that integrate the knowledge of individual human risk and the resultant impact on mission risk
  - With sufficient advance that the information can "enable" the design of future manned programs and missions
Level 1 Requirements/Program
Discipline Areas

- BMAC shall be organized around 5 discipline areas
  - Neurosensory
  - Cardiovascular/Pulmonary
  - Musculoskeletal
  - Regulatory Physiology
  - Behavior and Performance
- Critical issues shall be defined within these categories
- Monitoring capabilities shall be defined within these categories
- Risk assessment studies shall be defined within these categories
- Countermeasures shall be defined within these categories

Level 1 Requirements/Investigative Approaches

- Detailed investigative approaches shall be developed which includes three main functions for understanding risk
  - Operational Biomedical Monitoring (during all feasible scheduled operational activities)
  - Functional Monitoring - standardized, periodic testing of all body system categories in order to detect and monitor adaptative trends
  - Risk Assessment Studies - test protocols designed to evaluate specific risk issues
- A robust process shall be established which integrates the information from these three activities and along with any clinical health information provides an overall health status assessment capability
Operational Monitoring

- Monitoring during all operational activities in which human responses provides essential information associated with risk assessment - specific monitoring depends on mission design
  - EVA
  - During utilization of verified countermeasures
  - Launch
  - Landing/recovery
- Basic physiological and performance measurements
  - Heart rate
  - EKG/EMG
  - Blood pressure
  - Respiration rate
  - Body temperature/skin temperature
  - Motion
  - Doppler blood flow
  - Performance parameters
- Specific monitoring tailored to operational activity
- Monitoring activities must not increase risk of accomplishing the operational activity

Functional Monitoring

- Periodic functional tests conducted on each crewmember through the application of standardized stress and other tests
  - Determine status of all body systems
- Determine the time course and magnitude of adaptation
  - Efficacy of applied countermeasures
  - Determine what changes in countermeasure procedures should be implemented
- Attempt will be made to develop an optimized test set which will not require major changes during the course of the BMAC program
- Baseline measurement set
- Provides the major input for a long-term standardized data base of human responses to space flight
- Monitoring Schedule
  - Weekly (2 hours per crewman)
  - Bi-weekly (3 hours per crewman)
Functional Monitoring - Cont’d

- Specific test protocol TBD but considerations include
  - Single level known workload aerobic exercise test
  - Focused muscle strength test
  - Single level LBNP test
  - Selected pulmonary function tests
  - Sleep monitoring
  - Selected blood and urine tests
  - Selected neurosensory tests
  - Selected anthropometric tests
  - Selected behavioral and performance measurements
- Approach is to look at end-point parameters which indicate overall system status
- Contingency measurement/evaluation systems available to “follow-up” on any anomalous responses

Risk Assessment Studies

- A basic premise of BMAC is the ability to assess and understand human risk related to adaptation and operations in the space flight environment
  - These risks are not the same same as safety issues being addressed by SR&QA
- As noted previously, there is not currently a sufficiently complete data base to assign risk levels for the known issues (and new issues that may be uncovered)
- It will be necessary to implement specific test protocols or investigations designed to elucidate the necessary risk information
- AMAC Report used as a driving function for investigations
- Risk assessments are different from operational monitoring or functional testing
  - Specific investigative protocols with required number of subjects conducted over an identified number of flights
  - As required to identify specific risk parameters and/or levels
  - May or may not involve assessment of specific countermeasures
  - While exact manifesting of these studies is TBD, current experience has demonstrated a need of 1.5 hours/day/crewmember
Involving the Scientific Community

- One of NASA's charters is to provide access to space for conducting research
- The operational medical certification of humans and space flight systems is a NASA responsibility which cannot be "transferred"
- However, the breadth and challenges of BMAC will require that the expertise and knowledge of the life science community be utilized and included in the program
- BMAC will provide this collaboration within schedule and budgetary resources
- Two recommended approaches will be detailed later that address this issue
  - Resident Discipline Expert (RSE) Program
  - Focused NASA Research Announcements (NRAs)

Extramural Participation - Flight Opportunities

- BMAC traffic model based on 12/91 OSSA plan:
  - 1 double rack launched in 1997 (Phase 1)
  - 1 double rack launched in 1998 (Phase 1)
  - 2 double racks launched in 1999 (Phase 2)
- SSF traffic model provides 3 "utilization flights" (UF - assumed 13 day durations) in 1997, 3 UF s in 1998, and 2 UF in 1999
- Additional 12 "Mission Build" (MB - assumed 7 day duration) flights projected through the same timeframe
Standard Interface Rack - Concept

Hardware to Rack Standard Interfaces

Cooling
Power
Data
Fluid

Standard Interface Rack - Applications

SBI
BMAC
CHeCS
COTS
EDOMP
LSLE
EXPERIMENT UNIQUE
## Deliverables - End-Items/Rack 1

### Rack Mounted
- Activity Monitor (has stowed component)
- Automatic blood pressure system (ABPS)
- Body temperature - core
- Computer system, experiment control
- Data recorder, 12 channel
- Echocardiograph/doppler blood flow
- Gastrointestinal pH capsule system
- Physiological bio-potential recorder-12 lead
- Pulmonary analysis system - mass spec
- Pulse oximeter
- Pulse pressure measurement device
- Refrigerator/freezer
- Specimen labelling device

### Stowed
- Ambulatory blood pressure monitor (ABPM)
- Bar code reader
- Biowaste ID tag generator
- Blood centrifuge
- Blood collection systems
- CMI multi-test hypersensitivity system
- pH sensitive strips in fluid handling tools
- Fluid handling tools and system
- Electrode impedance meter
- Hematocit centrifuge
- Lower body negative pressure (LBNP)
- Physiological monitor (Vitalog)
- Stress and strain devices
- Holter monitor
- Temperature measurement kit
- Urine sample device
- Voice recorder

### Other Location
- Dynamometer, isometric-isokinetic
- Ergometer, dual cycle
- In-suit doppler bubble detector
Deliverables - End-Items/Rack 2

Rack Mounted
Auditory evaluation system
Biopotential Acquisition system
Breath hydrogen analyzer (microlyzer)
Carotid sinus baroreceptor stimulator
CO delivery/measurement system
Glovebox (GFE)

Stowed
Eye & head movement detection system
Gustatory & olfactory threshold tester
Physiological monitoring system (PMS)
Proprioceptive tester
Pulmonary analysis system - K2
Saliva collection unit
Spirometer
Three-D linear accelerometers (translation)
Video/data collection system

Deliverables - End-Items/Rack 3

Rack Mounted
Anthropometric measurement system
Body position detection system
Incentive field recording system S/W
Mass measurement - whole body
Microbial analyzer
Microscope system
Motion analysis system
Musculoskeletal overload trainer
Small mass measurement device
Visual sensory evaluation
Visual stimulator

Stowed
Macro-zoom lens
Middeck posture platform
Phantom head/torso
Sample prep device
Deliverables - End-Items/Rack 4

**Rack Mounted**
- Cognitive performance tester
- Electromagnetic stimulator
- Rotating chair system
- Virtual reality system

**Stowed**
- Muscle biopsy kit
The Gravitational Biology Facility (GBF) is a set of generic laboratory equipment needed to conduct research on Space Station Freedom (SSF), focusing on Space Biology Program science (Cell and Developmental Biology and Plant Biology). The GBF will be functional from the earliest utilization flights through the permanent manned phase. Gravitational biology research will also make use of other Life Sciences equipment on the space station as well as existing equipment developed for the space shuttle. The facility equipment will be developed based on requirements derived from experiments proposed by the scientific community to address critical questions in the Space Biology Program. This requires that the facility have the ability to house a wide variety of species, various methods of observation, and numerous methods of sample collection, preservation and storage. The selection of the equipment will be done by the members of a scientific working group (5 members representing cell biology, 6 developmental biology and 6 plant biology) who also provide requirements to design engineers to ensure that the equipment will meet scientific needs. All equipment will undergo extensive ground based experimental validation studies by various investigators addressing a variety of experimental questions. Equipment will be designed to be adaptable to other space platforms. The theme of the Gravitational Biology Facility effort is to provide optimal and reliable equipment to answer the critical questions in Space Biology as to the effects of gravity on living systems.
Gravitational Biology Facility Description

- Provides laboratory equipment items to conduct state-of-the-art, critical space life sciences research in:
  - Cell Biology
  - Developmental Biology
  - Plant Biology

- Includes common research equipment
  - Supports a wide range of specimen types
  - Various sample manipulation and preservation methods

- Hardware developed in evolutionary manner
  - Functional from Utilization Flights through PMC
Cell Biology Critical Questions

- How are cell functions influenced by gravity and or affected by microgravity?
  - Gene activation and function
  - Membrane/Signal transduction
  - Cellular differentiation/Cell division
  - Cellular immunology (immune cell function)

- Do single cells "sense" gravity directly (intracellularly) or indirectly (environmentally-mediated effect)?
  - In vitro macromolecular assembly
  - Oxygen tension and cellular respiration

Developmental Biology Critical Questions

- Which developmental mechanisms have evolved to be dependent on gravity (1-g)?
  - Oocyte maturation
  - Axis formation, pregastrulation & gastrulation

- How does gravity effect organogenesis and the development of anatomical structures?
  - Vestibular development
  - Skeletal growth and maturity
  - Structural muscle development and morphology

- Does the ontogeny of animals raised through more than one life cycle in microgravity differ from the 1-g classical pattern?
  - Insect, avian, aquatic and mammalian studies
Plant Biology Critical Questions

- What are the mechanisms that underlie gravity perception?
  - Altered gene expression

- Can plants successfully reproduce through more than one generation in space?
  - Seed production
  - Anthesis and Fertilization
  - Plant embryogenesis

- Are anabolic and catabolic pathways and the photosynthetic apparatus and pathway altered in microgravity?
  - Photosynthetic partitioning
  - Nutrient absorption and uptake
  - Alterations in cell wall synthesis

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GBF Science Working Group

Program Scientist:
- Dr. Thora Halstead, NASA HQ

Project Scientist and SWG chair: Deputy Project Scientist:
- Dr. Charles Wade, ARC
- Dr. William Knott, KSC

17 additional members:

5 Cell Biology

6 Plant Biology

6 Developmental Biology

Responsible for:
- Developing and reviewing GBF Reference Experiments
- Developing GBF Science Requirements for equipment items
- Providing science review and guidance in GBF equipment development effort

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Equipment Development Process

- Develop and Solicit Experiments for GBF
- Identify equipment items from GBF Reference Experiments
- Develop prioritized list of GBF hardware
- Science Working Group provides science requirements to engineers
- Studies to evaluate different hardware designs
- Develop approach for the design and development of GBF hardware
- Prototype hardware testing (ground-based, parabolic flights, shuttle experiments)

Reference Experiment Development

- Solicitation for reference experiments from the science community.
- Provided guidelines for:
  - areas of research
  - flight opportunities and time frames
  - justification for space flight
- SWG review, critique, and revision of experiments
- Solicitation for additional experiments for research areas not fully covered
Reference Experiment Set

- More than 125 experiments received (> 75 authors).
- Distribution between early flights (MTC) and PMC.
- Distribution over discipline specific research areas and critical questions.
- High degree of similarity of equipment required among the experiments and among the disciplines.

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GBF Specimen Habitats

√ Cell culture apparatus
  • Small Plant
  • Medium Plant
  • Insect
  • Egg Incubator
  • Small Aquatic (salt and fresh water)
  • Medium Aquatic
  • Rodent Birthing

• Large Plant
• Rodent Breeding
• Avian Hatchling
• Rodent Rearing
• Rodent Weanling to Adult
• Avian Adult
• Large Aquatic

Habitat characteristics:
- 1-g control
- Environmental control
- Video monitoring

√ = Multi-Discipline Equipment Item

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GBF Preservation & Storage Equipment

- Freezers (-196°C, -70°C, -20°C)
- Fixation capability
- Refrigerator
- Freeze Drier
- Snap Freezer
- Ambient Storage
- Refrigerator/Incubator

Purpose:
- Preserve and store samples on orbit
- Preserve samples during return to Earth for analysis

\( \sqrt{ } = \) Multi-Discipline Equipment Item

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GBF Manipulation & Analysis Equipment

- Fluid handling tools
- Compound Microscope (CCD)
- Work Area
- Dissection Equipment
- Dissecting Microscope
- Temperature Controlled Laboratory Centrifuge
- Data Storage
- Radiosotope Handling Equipment
- Digital Multimeter
- Ion Selective Electrodes
- Spectrophotometer
- Mass Measurement Device
- Electrophysiology Measuring Equipment
- Micromanipulation Device
- Luminometer

Purpose:
- Preparation of samples for ground-based analysis
- On orbit measurements and analysis

\( \sqrt{ } = \) Multi-Discipline Equipment Item

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Summary

Gravitational Biology Facility supports:

- Earliest life sciences experiments on Space Station Freedom
- Diverse specimen types and areas of research in Cell, Developmental, and Plant Biology
- Common laboratory equipment for life sciences research

For more information, contact:

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SSF Utilization Conference, Huntsville, Alabama, August 5, 1992
ABSTRACT

The goal of the Gas-Grain Simulation Facility project is to provide a microgravity laboratory to facilitate research relevant to exobiology (the study of the origin and evolution of life in the universe). Such a facility will also be useful in other areas of study important to NASA including planetary science, biology, atmospheric science, astrophysics, chemistry, and physics. To achieve this goal, the project will develop and support the GGSF, a modular facility-class payload planned for inclusion on Space Station Freedom. The GGSF will consist of an experiment chamber(s) supported by subsystems that provide chamber environment regulation and monitoring capabilities; sample generation, injection, positioning, and retrieval capabilities; and computer control, data acquisition and housekeeping capabilities. The facility will also provide analytical tools such as light-scattering measurement systems, aerosol size-spectrum measurement devices, and optical imaging systems.

As much as possible, facility components will be designed to be modular, allowing evolutionary growth of the facility capabilities. A modular design will also allow flexibility in facility configuration: provide for on-orbit integration of experiment unique equipment into the facility; and allow GGSF subsystems to be added, removed or exchanged with minimal crew interaction. To further minimize crew interaction requirements, the GGSF and each experiment to be performed on the GGSF are expected to make use of automation, telescience and artificial intelligence, allowing nearly autonomous operation.

Laboratory research enabled by the GGSF involves simulating and studying fundamental chemical and physical processes such as formation, growth, nucleation, condensation, evaporation, aggregation, coagulation, collision and mutual interaction of small (sub-micron to millimeter size) particles (e.g., crystals, powders, liquid droplets and dust grains). Twenty-two potential GGSF experiments involving such processes have been defined to date. Benefits of microgravity and specific potential experiments representative of the various disciplines will be discussed.

Currently, TRW is conducting a Phase A engineering reference design study for the GGSF. This design will be outlined and sketches of the concept shown. The GGSF science community met to discuss science requirements and this reference design at the third GGSF science workshop held in May of 1992 at the Desert Research Institute in Las Vegas, Nevada. The project is currently working toward launch of the GGSF to Space Station Freedom in 1998. GGSF science and hardware concept validation tests both ground and space-based are being planned with precursor experiments scheduled for launch on Shuttle in 1996.

Other work related to GGSF development includes four experiment concept studies for the Aerosol Physics Module, a precursor to the GGSF. These explore potential GGSF experiments dealing with smoke agglomerates, fractal particles, Titan atmosphere aerosols, and organic compound synthesis on growing particles. Another related study involves numerical modeling of coagulation and diffusion effects in the GGSF as a tool for experiment design and data analysis. Also related to GGSF development is an experiment just successfully completed in July on the Space Shuttle mission USML-1, which studied a method of dispersing solid particles in a microgravity environment.
Gas-Grain Simulation Facility (GGSF)

Space Station Freedom Utilization Conference
Huntsville, Alabama
August 3 - 6, 1992

Ken Greenwald
NASA Ames Research Center

Project Goals

- Support exobiology's goal to understand how cosmic, solar system, and planetary evolution have influenced the origin, evolution, and distribution of life and life-related molecules in the universe

- Provide a microgravity laboratory to facilitate research relevant to exobiology, biology, planetary science, astrophysics, atmospheric science, chemistry, and physics
Project History

1984-85: Workshops propose and develop concept

1987: Physics feasibility study by Martin Marietta
Workshop identifies science community, establishes experiment concept data base

1991: Science Working Group convenes
Phase A concept analysis/definition study begins for GGSF and precursor experiment
4 Aerosol Physics Module/GGSF concept studies funded

1992: Science Workshop - GGSF community examines Phase A design concept
USML-1 Glovebox Expt. tests particle dispersion method

Payload Data

• Readiness
  • Core Facility (MTC): 1998
  • Mature Facility (PMC): 2001

• Lifetime: > 10 years

• Mass (total): 700 Kg

• Size: 80"H x 42"W x 39"D (1 ISPR)

• Volume: ~ 1 m³

• Power: < 3 KW peak

• Location: Pressurized Laboratory
Science Objectives

To investigate fundamental chemical & physical processes involving suspended particles mainly in the sub-micron to millimeter size range (e.g., dust grains, crystals, combustion products, droplets, ...):

- Nucleation
- Condensation
- Evaporation
- Particle/Droplet Formation
- Particle/Droplet Growth
- Aggregation
- Coagulation
- Collisions
- Mutual Interactions

GGSF Science

EXOBIOLOGY

History of the biogenic elements
- Chemical evolution:
  - in the solar nebula
  - in the interstellar medium
  - in planetary atmospheres
- Growth of planetesimals

Prebiotic evolution

PLANETARY SCIENCE

ATMOSPHERIC SCIENCE

BIOLOGY

PHYSICS

CHEMISTRY

ASTROPHYSICS

- Study Gas-Grain Interactions
- Study Small Particle Interactions
- Study Phenomena Masked or Inhibited by Earth's Gravity
Exobiology

Question
What can planetary scale atmospheric chemistry reveal about the conditions on early Earth which led to the origin of life?

Potential GGSF Experiment
Titan's Atmospheric Aerosol Simulation
• Simulate formation and growth of organic haze
• Measure optical properties
• Determine chemical composition

Biology/Aerobiology

Question
What is the fate of airborne microbes, and how does microgravity affect aerosol disease spread in a confined space such as Space Station?

Potential GGSF Experiment
Airborne Bacteria in Microgravity
• Examine metabolism and growth, if any, of aerosolized microbes
• Determine the interrelationship between atmospheric trace gases (e.g., NO₅) and airborne microbes
• Determine how being airborne affects microbial pathogenicity
Astrophysics

Question
What are the properties of fractal materials? Do fractals play an important role in circumstellar and interstellar environments as well as in the early solar nebula?

Potential GGSF Experiment
Study of Fractal Particles
• Measure coagulation coefficients of silicates & metal grains
• Measure scattering & extinction efficiencies of aggregates
• Measure cohesive strength
• Study fractal structure
• Look for signatures to distinguish fractal aggregates from a distribution of particles

Planetary Science

Question
How do low energy collisions influence the behavior of ring structures such as those of Jupiter, Saturn, Uranus, and Neptune?

Potential GGSF Experiment
Planetary Ring Dynamics
• Study collision dynamics
• Measure energy loss in low velocity collisions
• Determine coefficients of restitution
• Analyze the transfer of linear to angular momentum
Atmospheric Science

Question
What are the properties of cirrus cloud crystals and what role do they play in the balance of the Earth’s atmospheric radiation budget? What is their effect on global warming?

Potential GGSF Experiment
Ice Scavenging and Aggregation: Optical and Thermal IR Absorption and Scattering Properties
- Study crystal growth
- Study aggregation
- Measure optical and thermal IR scattering and absorption properties
- Study scavenging of aerosols by ice crystals
## GGSF Strawman Investigations

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<td>2</td>
<td>Low-Energy Grain Interaction/Solid Surface Tension</td>
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<td>3</td>
<td>Cloud Forming Experiment</td>
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<td>Planetary Ring Particle Dynamics</td>
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<td>5</td>
<td>Aggregation of Fine Geological Particulates in Planetary Atmospheres</td>
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<td>6</td>
<td>Optical Properties of Low-Temperature Cloud Crystals</td>
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<td>7</td>
<td>Ice Scavenging and Aggregation</td>
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<td>8</td>
<td>Synthesis of Tholin and Measurement of its Optical Properties</td>
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<td>Metallic Behavior of Aggregates</td>
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<td>Organic Compound Synthesis on Surfaces of Growing Particles</td>
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<td>Crystallization of Protein Crystal-Growth Inhibitors</td>
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<td>Dipolar Grain Coagulation and Orientation</td>
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<td>Titan Atmospheric Aerosol Simulation</td>
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<td>14</td>
<td>Surface Condensation and Annealing of Chondritic Dust</td>
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<td>15</td>
<td>Studies of Fractal Particles</td>
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<td>Emission Properties of Particles and Clusters</td>
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<td>18</td>
<td>Study of Smoke Agglomerates</td>
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<td>19</td>
<td>Airborne Bacteria in Microgravity</td>
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<td>20</td>
<td>Infrared Emissivity of Extraterrestrial Particles</td>
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<tr>
<td>21</td>
<td>Radiation-Induced Rotation of Interplanetary Dust</td>
</tr>
<tr>
<td>22</td>
<td>Dynamics and Evaporation of Clusters of Drops in Vortical Flows</td>
</tr>
</tbody>
</table>
GGSF Strawman Experiment Investigators

1 Weidenschilling, *Planetary Science Institute*

2 Sievers and Thompson, *Cornell University*

3 Hudson, *Desert Research Institute*

4 Bridges, *U.C. Santa Cruz*

5 Marshall, *Arizona State University*

6 Pope, ARC and Tomasko, *U. of Arizona*

7 Hallett, *Desert Research Institute*

8 Khare, *Cornell University*

9 Traver, *Johns Hopkins University*

10 Oberbeck, *Ames Research Center*

11 Raymond, *U. of South Alabama*

12 Freund, *SETI Institute*

13 Scattergood, S.U.N.Y. and McKay, *ARC*

14 Rietmeijer and McKinnon, *U. of New Mexico*

15 Nuth, *Goddard and Stephens, Los Alamos Lab.*

16 Allamandola, *Ames Research Center*

17 Rhim, *Jet Propulsion Laboratory*

18 Mulholland, *NIST*

19 Mancinelli, *SETI Institute*

20 Goebel, *Ames Research Center*

21 Misconi, *Space Research Institute*

22 Bellan, *Jet Propulsion Laboratory*
Benefits of Microgravity to GGSF

• Suspension times increased
  • Permits long duration aerosol studies
  • Enables low-velocity collision experiments

• Buoyancy-driven convection reduced ($\Delta T_{cr} \propto 1/g$)

• Allows low energy interactions that are masked by gravitational forces on Earth

• Fractals and other gravitationally unstable (at 1 g) objects may be studied

Modular Design Concept (Phase A)

• Interchangeability of subsystems accommodates a broad range of experiments

• Allows for new experiments and technology upgrades

• Four interchangeable chambers

<table>
<thead>
<tr>
<th>Function</th>
<th>Temperature (K)</th>
<th>Pressure (bar)</th>
<th>Volume (Liters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core</td>
<td>150 to 400</td>
<td>$10^{-6}$ to 1</td>
<td>67</td>
</tr>
<tr>
<td>Low Temp.</td>
<td>40 to 400</td>
<td>$10^{-6}$ to 3</td>
<td>4.2</td>
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<tr>
<td>High Temp</td>
<td>300 to 1200</td>
<td>$10^{-6}$ to 1</td>
<td>8.2</td>
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<tr>
<td>High Vacuum</td>
<td>60 to 300</td>
<td>$10^{-10}$ to 1</td>
<td>4.2</td>
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The 4 Chambers Accommodate the Following:

<table>
<thead>
<tr>
<th>Physical Objectives</th>
<th>Generation Methods</th>
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<tbody>
<tr>
<td>Aggregation</td>
<td>Low Temp. Nuc./Condensation</td>
</tr>
<tr>
<td>Biological</td>
<td>High Temp. Vapor Formation</td>
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<tr>
<td>Condensation/Nucleation</td>
<td>Solid Particle Dispersion</td>
</tr>
<tr>
<td>Crystal Formation</td>
<td>• Single/Small Number</td>
</tr>
<tr>
<td>Particle Dynamics/Collisions</td>
<td>Combustion (Smoke/Soot)</td>
</tr>
<tr>
<td>Spectral/Optical Properties</td>
<td>Liquid Aerosol Dispersion</td>
</tr>
<tr>
<td>Synthesis of Compounds</td>
<td>• Single/Small # of Drops</td>
</tr>
<tr>
<td></td>
<td>Radiation-Induced Synthesis</td>
</tr>
</tbody>
</table>

**Generation Methods**

- **Low Temp. Nuc./Condensation**
- **High Temp. Vapor Formation**
- **Solid Particle Dispersion**
  - Single/Small Number
- **Combustion (Smoke/Soot)**
- **Liquid Aerosol Dispersion**
  - Single/Small # of Drops
- **Radiation-Induced Synthesis**
Core Chamber

- Sample Generation Port
- UV Photolysis Source, RF Source
- Visible UV Detector Array
- Cryo Cooler Interface
- Sensors Electrical Feedthrough
- Backlighting for Camera in Port
- Heaters Electrical Feedthrough
- CCD Camera Port
- Front Lighting for Camera
- HeNe Laser, Colimated Broad Band Source
- Detector Ring
- Sample Generation Port
- Vent, Pressure Sensor, Gas Inlet, Sample Collection Gas Chromatography
Future Plans

- Science and Hardware Concept Validation
  - Ground-based KC-135, drop tower; space-based Shuttle middeck and Spacelab opportunities
  - Reduces hardware development risks
  - Provides early science return

- GGSF Technology Workshop

- GGSF Science Workshop
RESEARCH OPPORTUNITIES WITH THE CENTRIFUGE FACILITY

Presented by Glenn A. Funk, Ph.D.
GE Government Services
NASA Ames Research Center

ABSTRACT

The Centrifuge Facility on Space Station Freedom will consist of a 2.5-meter diameter Centrifuge accommodating two concentric rings of Habitats and providing variable g forces between 0.01g and 2.0g; Modular Habitats providing housing and life support for rats, mice, and plants; a Habitat Holding System providing power, water, airflow and other utilities to several Modular Habitats; and a Life Sciences Glovebox, an isolated work volume accommodating simultaneous operations by at least two scientists and providing lighting, airflow, video and data access, and other experiment support functions.

The Centrifuge Facility will enable long-duration animal and plant microgravity research not previously possible in the NASA flight research program. It will offer unprecedented opportunities for use of on-board 1-g control populations and statistically significant numbers of specimens. On-orbit 1-g controls will allow separation of the effects of microgravity from other environmental factors. Its selectable-g and simultaneous multiple-g capabilities will enable studies of gravitational thresholds, the use of artificial gravity as a countermeasure to the effects of microgravity, and ready simulation of Lunar and Martian gravities.

Many exciting research opportunities stem from the permanent presence of the Centrifuge Facility on-orbit. Long-duration exposure to microgravity will permit extended studies directly relevant to the health and welfare of crew members on long space mission. It will also allow studies that encompass both significant portions of a subject’s life span and, of special interest, studies that examine microgravity effects over several generations of both plants and animals. In the process of supporting multigeneration studies, the Facility will simultaneously support the derivation of spaceadapted colonies of subjects for future use. The permanent presence of scientist-astronauts will enable real-time experiment manipulation, alteration, and replication. To capitalize on this capability, many Facility elements are being designed for maximum flexibility and on-orbit reconfigurability.

The Centrifuge Facility will accommodate studies in all life sciences disciplines, from behavioral experiments to detailed investigations of physiologic systems, e.g., cardiovascular, musculoskeletal, and neurovestibular. It will support the collection of on board samples and fixation of samples for return to Earth for sophisticated analyses which cannot be performed on-orbit. However, there will be a wide variety of on board laboratory equipment and analytical instruments. While initially designed for use with rodents and plants, it will ultimately accommodate a wide range of biospecimens, including small primates, fish, amphibians, arthropods, and microbial and cell cultures. The Facility will provide variable housing configurations, well-controlled environmental parameters, water and nutrient delivery, waste management, video, and access to biotelemetry and other data. It will also accommodate a variety of add-on experiment-unique equipment such as special video cameras, unique specimen chambers, and custom sensors.

For the first time, the Centrifuge Facility and Space Station Freedom will permit systematic research to understand the physiological and biochemical changes in living organisms that take place in the space environment.
RESEARCH OPPORTUNITIES WITH
THE CENTRIFUGE FACILITY

Glenn A. Funk, Ph.D.
GE Government Services
NASA Ames Research Center
Moffett Field, CA

THE CENTRIFUGE FACILITY

- CENTRIFUGE
  - 2.5-meter diameter; provides variable-g capability (0.01-2.0 g)
- MODULAR HABITATS
  - Interchangeable between Centrifuge, Holding System and Glovebox
  - Provide housing and life support for plants and rodents
- HABITAT HOLDING SYSTEM
  - Provides utilities and services to Modular Habitats
- LIFE SCIENCES GLOVEBOX
  - Provides biosolated work volume for experiment and maintenance procedures
- RODENT TRANSPORTER
  - Provides housing for rodents during transport to orbit
ACCOMMODATIONS

- THE CENTRIFUGE FACILITY WILL SUPPORT ALL OF NASA'S LIFE SCIENCES RESEARCH DISCIPLINES:
  - Cardiopulmonary  - Cell & Developmental Biology
  - Musculoskeletal  - Regulatory Physiology
  - Neuroscience     - Environmental Health & Radiation
  - Plant Biology    - Behavior and Performance

- THE CENTRIFUGE FACILITY WILL ACCOMMODATE A VARIETY OF DIFFERENT BIOSPECIMEN TYPES:
  - Initially: Rats, mice, and plants
  - Post-2000: Squirrel monkeys
  - Ultimately: Fish, birds, amphibians, arthropods, microbial and tissue cultures, etc.

WHAT DOES THE CF OFFER?

- ON-BOARD CONTROL POPULATIONS
- STATISTICALLY SIGNIFICANT NUMBERS OF SPECIMENS
- FRACTIONAL GRAVITY CAPABILITIES
  - Hypo-g studies: Gravitational thresholds
    Lunar, Mars and other g simulations
    Countermeasures
  - Hyper-g studies: Extension of ground-based centrifuge studies
    Countermeasures
- LONG-DURATION MICROGRAVITY EXPOSURE
  - Significant fraction of normal life span
  - Multigeneration studies
  - Space-adapted colonies
ASSOCIATED FEATURES

- **ON-BOARD ADJUNCT CAPABILITIES**
  - *Gravitational Biology Facility*: a suite of generic laboratory equipment and biospecimen habitats to support the Cell & Developmental and Plant Biology disciplines
  - *Laboratory Support Equipment*: a suite of generic laboratory instruments to support life sciences microgravity research, e.g., refrigerators, freezers, mass measurement devices, etc.
  - *Biomedical Monitoring and Countermeasures*: common equipment items
  - *Crew Health Care System*: common equipment items
  - Scientist/Astronaut crew
  - Telescience/Remote coaching (eventually)

- **ACCOMMODATION OF EXPERIMENT-UNIQUE EQUIPMENT (EUE)**
  - Unique specimen chambers (e.g., mating, birthing/rearing)
  - Specialized video cameras (e.g., lenses, spectral qualities)
  - Custom sensors

FLIGHT VERIFICATION SCIENCE

- **THREE SEQUENTIAL 90-DAY FLIGHT INCREMENTS ONLY**
- **PLANNED FOR YEAR 2000**
- **GOAL IS TO VERIFY THE PROPER PERFORMANCE OF THE CENTRIFUGE FACILITY ON-ORBIT**
  - Engineering
  - Science
- **INVESTIGATORS WILL BE SOLICITED**
  - Normal Headquarters-directed solicitation process
  - Research plans must meet verification goals first
  - Research plans must minimize need for EUE
ONGOING SCIENCE

- ONGOING SCIENCE PROGRAM TO BEGIN FOLLOWING SUCCESSFUL COMPLETION OF FLIGHT VERIFICATION
- ANTICIPATED START IN YEAR 2001
- NORMAL HEADQUARTERS-DIRECTED SOLICITATION PROCESS
- 90-DAY INCREMENTS WILL BE DISCIPLINE-ORIENTED
- WILL PROVIDE:
  - On-orbit sampling and storage, some processing and analysis
  - Data acquisition, processing, storage and downlink

STATUS AND PLANS

- CENTRIFUGE FACILITY HARDWARE
  - Phase A and B studies complete
  - Phase C/D RFP released July 7, 1992
  - Phase C/D start 1993

- CENTRIFUGE FACILITY SCIENCE
  - Verification increment science NRAs - 1994
    Investigators to be on-board by CDR (early 1995)
    Verification experiment development 1995-2000
  - Ongoing science NRAs ~1997
    Experiment development ~1998 on
CONCLUSION

THE CENTRIFUGE FACILITY WILL MAKE POSSIBLE THE SYSTEMATIC RESEARCH NECESSARY TO UNDERSTAND THE PHYSIOLOGICAL, BIOCHEMICAL AND GENETIC CHANGES IN LIVING ORGANISMS THAT TAKE PLACE IN THE SPACE ENVIRONMENT.
The CELSS Test Facility (CTF) is being developed for installation on Space Station Freedom (SSF) in August 1999. It is designed to conduct experiments that will determine the effects of microgravity on the productivity of higher (crop) plants. The CTF will occupy two standard SSF racks and will accommodate approximately one square meter of growing area and a canopy height of 80 cms. The growth volume will be isolated from the external environment, allowing stringent control of environmental conditions. Temperature, humidity, oxygen, carbon dioxide, and light levels will all be closely controlled to prescribed setpoints and monitored. This level of environmental control is needed to prevent stress and allow accurate assessment of microgravity effect (10^{-3} to 10^{6} \times g). Photosynthetic rates and respiration rates, calculated through continuous recording of gas concentrations, transpiration and total and edible biomass produced will be measured. Toxic byproducts will be monitored and scrubbed. Transpiration water will be collected within the chamber and recycled into the nutrient solution. A wide variety of crop plants, e.g., wheat, soy beans, lettuce, potatoes, can be accommodated and various nutrient delivery systems and light delivery systems will be available. In the course of its development, the CTF will exploit fully, and contribute importantly, to the state-of-art in closed system technology and plant physiology - Controlled Environmental Agriculture, sensors and instrumentation, plant growth environment modeling, atmosphere control and gas concentration maintenance among a few.
AUGUSTINE REPORT: OF ALL THE CRITICAL ELEMENTS FOR LONG DURATION SPACE FLIGHT, CLOSED ECOLOGICAL SYSTEMS REMAIN AMONG THE LEAST UNDERSTOOD AND THE MOST CHALLENGING

- BIOREGENERATIVE LIFE SUPPORT SYSTEMS WILL OPERATE WITH A COMBINATION OF BIOLOGICAL (e.g., HIGHER PLANTS (WHEAT,)), PHYSICAL AND CHEMICAL COMPONENTS, TO RECYCLE THE WATER, OXYGEN, FOOD AND CARBON DIOXIDE NEEDED BY HUMAN CREWS

- THE NASA CELSS PROGRAM IS CHARGED WITH DEVELOPMENT OF THE SCIENCE AND TECHNOLOGIES NECESSARY TO CONSTRUCT BIOREGENERATIVE LIFE SUPPORT SYSTEMS FOR USE IN SPACE

- THE CELSS TEST FACILITY IS BEING DESIGNED TO GROW HIGHER PLANT CROPS ON SPACE STATION FREEDOM UNDER STRINGENTLY CONTROLLED ENVIRONMENTAL CONDITIONS FOR THE PURPOSE OF DETERMINING CROP PRODUCTIVITY
THE CELSS PROGRAM HAS SUPPORTED MAJOR RESEARCH EFFORTS THAT HAVE FOCUSED ON HIGHER PLANT PRODUCTIVITY

- PRODUCTIVITY IS DEFINED AS THE RATE OF PRODUCTION OF FOOD, WATER OR OXYGEN PER UNIT OF RESOURCE USE (E.G., AREA, VOLUME, KW POWER, ETC.)
- CELSS RESEARCH HAS EXPLORED THE UPPER LIMITS OF HIGHER PLANT PRODUCTIVITY AT 1 x g BY INVESTIGATING THE EFFECTS OF ENVIRONMENTAL CONDITIONS ON PLANT GROWTH RATES

- FOR EXAMPLE, WHEAT CROPS GROWN UNDER RIGOROUSLY CONTROLLED ENVIRONMENTAL CONDITIONS EXCEED FIELD PRODUCTIVITY FIVE-FOLD

A MAJOR UNKNOWN IS THE PRODUCTIVITY OF PLANTS IN SPACE: IN ORBIT AT MICRO-GRAVITY (10^-6 TO 10^-3 x g), ON THE MOON'S SURFACE (0.16 x g) AND ON MAR'S SURFACE (0.38 x g)

- WHILE THE INITIAL USE OF THE CELSS TEST FACILITY WILL BE ON SPACE STATION FREEDOM, THE FACILITY CAN BE ADAPTED TO STUDY PLANT GROWTH ON THE MOON'S SURFACE AS A LABORATORY INSTRUMENT IN AN EARLY LUNAR BASE
Science and Technology Working Group

Robert MacElroy NASA/AMES Research Center
John Tremor Biometics/AMES Research Center
Marcel Andre Cadarache Research Center (CEA) France
Charles Blackwell University of Texas/AMES Research Center
Ray Buda U Wisconsin/WCSAR
Joe Cowles Virginia Technical University
Joe Gale Hebrew University of Jerusalem
Arthur Galston Yale University
Gary Johns NASA/AMES Research Center
William Knott NASA/Kennedy Space Center
Marv Littge University of Colorado/Aerospace Engineering Science
Ralph Mitchell Harvard University/Division of Applied Science
Gary Mitchell Purdue University/Department of Horticulture
Frank Salisbury Utah State University/Plants Soils and Biometeorology Department
Tyler Volk New York University
Richard Wisniewski NASA/AMES Research Center

Controllable Environmental Conditions

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<tr>
<th>Parameter</th>
<th>Condition</th>
<th>Tolerance</th>
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<td>Temperature</td>
<td>18-40 deg C</td>
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<tr>
<td>Humidity</td>
<td>60-80% RH</td>
<td>± 10%</td>
</tr>
<tr>
<td>O₂ Level</td>
<td>5-23.7 kPa</td>
<td>± 5%</td>
</tr>
<tr>
<td>CO₂ Level</td>
<td>300-5000 µmol/mol</td>
<td>± 10 µmol/mol</td>
</tr>
<tr>
<td>Lights</td>
<td>on/off</td>
<td></td>
</tr>
<tr>
<td>Light Intensity</td>
<td>200-2000 µmol/m²/s</td>
<td>± 5%</td>
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</tbody>
</table>

Crop:
- Cultivars
- Species
- Genetic Engineering
- Polyculture
AN ON-ORBIT VIEWPOINT OF LIFE SCIENCES RESEARCH

Presented by Byron K. Lichtenberg
Omega Aerospace, Inc.
Consultant- Boeing

ABSTRACT

As a Payload Specialist who has flown on two space shuttle missions and a life science researcher, I want to present several issues that impact life science research in space. During early space station operations, life science and other experiments will be conducted in a time-critical manner, long-duration human experiments will generally not be done, and there will be the added duties of both space shuttle and space station systems operation (and the concomitant training overhead).

Life sciences research is different from other science research done in space because the crew is involved both as an operator and as a subject. There is a need for pre- and post-flight data collection as well as inflight data collection. It is imperative that the life science researcher incorporate the crewmembers into their team early in the training cycle to fully explain their science and make the crew aware of the importance and sensitivities of their experiment.

During the pre-flight phase, the crew is incredibly busy with a myriad of duties. Therefore, it is difficult to get "pristine" subjects for the baseline data collection. There are also circadian shifts, travel and late nights to confound the data. During this time it is imperative that the researcher develop, along with the crew, a realistic estimate of crew-time required for their experiment.

Inflight issues that affect the researcher are the additional activities of the crew, the stresses inherent in spaceflight, and the difficulty of getting early in-flight data. During SSF activities the first day or two will be taken up with rendezvous and docking. Other issues are the small number of subjects on any given flight, the importance of complete and concise procedures, and the vagaries of on-board data collection.

Postflight, the crew is tired and experiences a "relaxation." This along with circadian shifts, and rapid re-adaptation to 1-g make immediate post-flight data collection difficult.

Finally, the blending of operational medicine and research always results in either competition for resources (crew time, etc) or can influence the physiological state of the crew member by imposing mandated countermeasures. However, the unique opportunity to conduct research in an environment that cannot be duplicated here on Earth outweighs all of the "challenges" that exist for space life researchers!
CREW HEALTH

Presented by Roger Billica, M.D.
Medical Operations Branch
NASA Johnson Space Center

ABSTRACT

Crew health concerns for Space Station Freedom are numerous due to medical hazards from isolation and confinement, internal and external environments, zero gravity effects, occupational exposures, and possible endogenous medical events. The operational crew health program will evolve from existing programs and from life sciences investigations aboard Space Station Freedom to include medical monitoring and certification, medical intervention, health maintenance and countermeasures, psychosocial support, and environmental health monitoring. The knowledge and experience gained regarding crew health issues and needs aboard Space Station Freedom will be used not only to verify requirements and programs for long duration space flight but also in planning and preparation for Lunar and Mars exploration and colonization.
CREW HEALTH

- How does SSF utilization depend upon crew health?
- How does the field of Space Medicine plan to utilize SSF?
IMAGINE...

- Health (short term, long term)
- Well-being
- Performance
- Mission schedule
- Mission goals
- Mission success
- Program viability

MEDICAL HAZARDS OF SPACE FLIGHT

1. Zero - Gravity
   a. Physiological changes (cardiovascular, musculoskeletal, etc)
   b. Illnesses (SMS)

2. Isolation / Confinement
   a. Psychosocial stress
   b. Nutritional deficiency
   c. Infectious disease

3. Environment
   a. External (radiation, vacuum)
   b. Internal (noise, toxic exposure, vibration)

4. Space flight (general)
   a. Trauma
   b. Endogenous illness
   c. G-forces (acceleration, impact)
COMPREHENSIVE HEALTH CARE PROGRAM

1. Medical Assessment and Certification
2. Countermeasures Implementation
3. Medical Intervention
4. Psychosocial Support
5. Environmental Health Monitoring

for ALL mission phases:
   Preflight - Inflight - Postflight

NASA Medical Care Systems for Space Flight

- Provide monitoring, diagnosis and treatment for:
  - first aid and routine simple medical events
  - emergencies (incl. decompression sickness)
  - dental
  - stabilization and transport for more serious illnesses and injuries

- Space Shuttle = Shuttle Orbiter Medical System (SOMS)

- Space Station = Crew Health Care System (CHeCS)
  - Health Maintenance Facility
  - Environmental Health System
  - Exercise Countermeasures Facility
SPACE MEDICINE UTILIZATION OF SSF

1. Establish baselines and norms for humans in space, isolation and confinement (closed systems.)
2. Develop and verify monitoring and countermeasures.
3. Gain operational experience in remote health care, verify procedures and protocols.
4. Testbed for Lunar and Mars health care systems.

OPERATIONAL RESEARCH AND DEVELOPMENT

1. Medical intervention technologies
2. Remote monitoring and diagnostic technologies (non-invasive)
3. Circadian shifting
4. Telemedicine
5. Decontamination and toxic management strategies
6. Medical computer informatics and expert systems
7. Extended life pharmaceuticals
8. Blood and fluid replacement systems
9. Radiation protection
10. Crew selection and psychosocial support
11. Packaging logistics
GOAL

PROVIDE A PROGRAM OF COMPREHENSIVE HEALTH CARE NECESSARY TO ENABLE A HEALTHY AND PRODUCTIVE CREW THAT IS ABLE TO ACCOMPLISH MISSION GOALS, AND TO AVOID LONG TERM NEGATIVE CREW HEALTH CONSEQUENCES.

QUESTIONS?
SPACE STATION FREEDOM AS AN ENGINEERING EXPERIMENT STATION: AN OVERVIEW

Presented by M. Frank Rose
Space Power Institute
Auburn University

ABSTRACT

It is one of NASA's missions to provide the technological underpinnings for space flight, be it manned or unmanned. As a consequence, the relevant technologies such as power, propulsion, life support and materials technologies are investigated throughout the space community. The results of these investigations quite often produce laboratory prototypes which are sometimes an order of magnitude better than the technology employed in the currently flying spacecraft. Attempts to bring these developments to the point where they will readily be used by spacecraft designers invariably stumbles on the issue of space qualification. The process to do this is long and, while terrestrial simulation can give confidence, nothing suffices for full qualification like time in space.

In this presentation, the premise that Space Station Freedom has great utility as an engineering experiment station will be explored. There are several modes in which it can be used for this purpose. The most obvious are space qualification, process development, in space satellite repair, and materials engineering. The range of engineering experiments which can be done at Space Station Freedom run the gamut from small process oriented experiments to full exploratory development models. A sampling of typical engineering experiments are discussed in this session. First and foremost, Space Station Freedom is an elaborate experiment itself which, if properly instrumented, will provide engineering guidelines for even larger structures which must surely be built if mankind is truly "outward bound". Secondly, there is the test, evaluation and space qualification of advanced electric thruster concepts, advanced power technology and protective coatings which must of necessity be tested in the vacuum of space. The current approach to testing these technologies is to do exhaustive laboratory simulation followed by shuttle or unmanned flights. Third, the advanced development models of life support systems intended for future space stations, manned mars missions, and lunar colonies can be tested for operation in a low gravity environment. Fourth, it will be necessary to develop new protective coatings, establish construction techniques, evaluate new materials to be used in the upgrading and repair of Space Station Freedom. Finally, the industrial sector, if it is ever to build facilities for the production of commercial products must have all the engineering aspects of the process evaluated in space prior to a commitment to such a facility.

The necessity for EVA, an engineering laboratory, and the appropriate compliment of instrumentation will be discussed in terms of what is now planned for Space Station Freedom and what would ideally be needed. The link with transportation will be discussed in terms of cost, lift capability and current state of the art.
SPACE STATION FREEDOM
UTILIZATION CONFERENCE

SPACE STATION FREEDOM AS AN ENGINEERING EXPERIMENT STATION
AN OVERVIEW

PRESENTED TO
SPACE STATION FREEDOM UTILIZATION CONFERENCE
AUGUST 3 - 6, 1992

M. FRANK ROSE
SPACE POWER INSTITUTE
231 LEACH CENTER
AUBURN UNIVERSITY, AL

POWER LEVEL GROWTH

SDI HAS MISSION REQMTS COVERING THIS SPACE AND FACTORS OF 10 -100 BEYOND (POWER) BUT SHORT DURATION - CW POWER COMPARABLE FOR A VARIETY OF NEEDS

NOMINAL PLANETARY BASES
GROWTH SPACE STATION
INTERPLANETARY TRANSPORT
DEEP SPACE EXPLORATION
SAMPLE RETURN MISSIONS
SPACE MATERIALS PROCESSING

CONVENTIONAL SPACECRAFT APPLICATIONS
COMMERCIAL APPLICATIONS
SURFACE EXPLORATION VEHICLES

GROWTH PLANETARY COLONIES
ADVANCED TRANSPORTATION
EXTRA-SOLAR MISSIONS
ASSUMPTIONS

- MAN IN SPACE IS INEVITABLE AND WILL BE A PARTNERSHIP WITH HIS MACHINES
- COLONIZATION AND SCIENTIFIC OUTPOSTS ON THE MOON AND MARS WILL OCCUR
- "COMMERCIALIZATION" OF SPACE WILL OCCUR

CONSEQUENCES

- SCIENTIFIC LABORATORIES TO STUDY FUNDAMENTAL PHENOMENA UNIQUE TO THE SPACE ENVIRONMENT
- ENGINEERING LABORATORIES TO SPACE QUALIFY AND "PROOF" TEST ADVANCED SYSTEMS/COMPONENTS FOR EXPLORATION AND COMMERCE
- MUST HAVE A SPACE STATION - NOTHING SPACE QUALIFIES LIKE TIME IN SPACE

SPACE STATION FREEDOM IS ANOTHER NASA FIELD STATION WITH THE SAME COMPLIMENT OF TASKS AS EXISTING CENTERS - ONLY 300 MILES FROM FOGGY BOTTOM, UNFORTUNATELY IT IS UP-HILL BOTH WAYS

SSF AS AN ENGINEERING EXPERIMENT

ONLY COUNTRY IN THE WORLD WHO WILL KNOW HOW TO BUILD LARGE SPACE STRUCTURES - IMPORTANT TO COMMERCIALIZATION AND EXPLORATION
Space power technologies as related to mission duration

SPACE STRUCTURES TECHNOLOGY

- EFFICIENT RELIABLE POWER - SSF REPRESENTS A MAJOR EXPERIMENT IN POWER FOR FUTURE FACILITIES
- MATERIALS AND THEIR INTERACTION WITH THE SPACE ENVIRONMENT
  - THOSE ON THE STATION
  - NEW MATERIALS FOR NEXT GENERATION
- THERMAL MANAGEMENT FOR LARGE STRUCTURE
- PROPULSION AND STATION KEEPING
- EFFECTS OF OPERATIONS
- DYNAMICS OF THE STRUCTURE
ENGINEERING EXPERIMENT STATION

- Evaluate new life support system concepts, components and systems
- Man's ability to function and prosper in the space environment
  - Human factors
  - Productivity
  - Man - machine teams
- Space qualify
  - Power
  - Propulsion
  - Electronics
  - Materials
- Assembly and repair of complex spacecraft
  - Node in the lunar and Mars missions
  - Refurbish and repair satellites along the lines of the shuttle crew experience
  - Assemble, test, space qualify components, systems, etc intended for commercial operations

AERONAUTICS AND SPACE TECHNOLOGY
CODE - R

- Responsible for developing the technological underpinnings of any future space endeavour
- Has developed many component technologies which represent significant improvements over flight hardware
- Needs to advance to technology demonstrators
  - Terrestrial
  - Space demonstrator
- Space qualify and transfer to the aerospace community

Space Station Freedom should be the laboratory for transitioning Code - R technology to the space fleet
• **Conclusion:** OAST has an enormous spectrum of science and technology which must form the basis of a permanent space infrastructure. SSF's greatest value to OAST is as an engineering experiment station where advanced technologies can be researched, developed and space qualified, SEI hardware space tested, engineering guidelines for future space hardware determined, and commercial prototyping established.

**Recommendation:** OAST should promote this interpretation of SSF insisting that SSF is much more than a platform for life sciences and microgravity materials R&D. OAST should coordinate with Code C to actively promote a joint constituency. OAST should constantly negotiate with SSF to insure maximum man in the loop experimentation aboard SSF and obtain NASA administrator support for this.

August 3, 1992

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• **Conclusion:** The SSF planning cycle for experimental access is estimated to be greater than 5 years and needs to be streamlined and made user friendly.

**Recommendation:** OAST should insist on standardization of procedures and equipment, reduction of "paperwork", and the establishment of a field center office whose function is to guide and expedite the process of "getting an experiment through the system". In general, it should push for a time line of 1-3 years. Rapid response SARR type payloads should be minimal time response with large complicated experiments taking no more than four years.

August 3, 1992
OAST SECURE A MANDATE
FROM THE NASA ADMINISTRATOR TO HEAVILY
USE SSF TO PURSUE THE RELEVANT SCIENCE,
ESTABLISH ENGINEERING GUIDELINES,
SPACE QUALIFY PROMISING TECHNOLOGIES
AND TEST PROTOTYPE SYSTEMS INTENDED
FOR COMMERCIAL ENTERPRISES AND MAN'S
INEVITABLE PERMANENT PRESENCE IN
SPACE—

August 3, 1992

KEY ISSUES
ENGINEERING EXPERIMENT STATION

- WILL THE SSF AS FINALLY BUILT BE ADEQUATE
  - WORK SPACE
  - EQUIPMENT COMPLIMENT
  - PERSONNEL
- CAN PROCEDURES BE STREAMLINED TO MINIMIZE TIME NEEDED
  TO TAKE AN EXPERIMENT TO THE STATION
- CAN EVA WORKLOAD BE SCHEDULED TO SERVICE STATION AND
  MAJOR EXTERNAL EXPERIMENTS
- COST OF TIME AT STATION
- COST OF TRANSPORTATION
- SUPPORT OF THE CONGRESS AND THE AMERICAN PEOPLE
It must be remembered that there is nothing more difficult to plan, more doubtful of success, nor more dangerous to manage than the creation of a new system. For the initiator has the enmity of all who would profit by the preservation of the old institution and merely lukewarm defenders in those who would gain by the new ones.

Machiavelli, "The Prince", 1513.

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### SPACE STATION FREEDOM UTILIZATION CONFERENCE

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<tr>
<th>Time</th>
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<td>Overview—Dr. M. Frank Rose</td>
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<td>9:00</td>
<td>Precursor Space Station Experiments—Sherwin M. Beck, Director, Systems</td>
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<td>Analysis and Engineering, Space Station Freedom Office, NASA LaRC</td>
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<td>Model Identification Experiments—Dr. Bradley Hanks, Head,</td>
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<td>Spacecraft Dynamics Office, NASA LaRC</td>
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<td>9:40</td>
<td>Instrumented Space Station—Dr. Lenwood G. Clark, Acting Deputy Manager,</td>
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<td>Earth Probes Program, NASA Headquarters</td>
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<tr>
<td></td>
<td>Middeck O-Z Dynamics Experiments—Professor Edwin F. Crawley,</td>
</tr>
<tr>
<td></td>
<td>Department of Aeronautics and Astronautics, MIT</td>
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<tr>
<td>10:00</td>
<td>Break</td>
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<tr>
<td>10:30</td>
<td>Potential Attached Payloads—Don E. Avery, Space Station Utilization</td>
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<td>Office, NASA LaRC</td>
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<td></td>
<td>Spacecraft, Materials &amp; Coatings—Wayne Slemp, Applied Materials Branch,</td>
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<td>Materials Division, NASA LaRC</td>
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<td>Materials Experiment Opportunities—Robert Schmidt, Center for Materials</td>
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<td>&amp; Structures, Case Western Reserve University</td>
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<td>11:30</td>
<td>Potential Propelled Payloads—Roy McIntosh, Head, Advanced Developments</td>
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<td>&amp; Flight Experiment Section, NASA Goddard Space Flight Center</td>
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<tr>
<td></td>
<td>Two-Phase Thermal Flow—Roy McIntosh</td>
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<td></td>
<td>Life Support &amp; Thermal Control for Space Station—Liese A. Dell-Rauman,</td>
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<td></td>
<td>System Engineering Analysis Office, NASA Johnson Space Center</td>
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ABSTRACT

The NASA Office of Aeronautics and Space Technology uses the In-Space Technology Experiments Program (IN-STEP) as the primary management vehicle to pursue innovative and potentially high payoff space technology experiments. The purpose of this presentation is to provide an overview of the IN-STEP approach in developing precursor Space Station experiments; identify those experiments now in the program; review the key points of the IN-STEP 1992 Announcement of Opportunity; and describe the OAST in-space technology experiments development process.
Space Station Utilization Conference

Precursor Space Station Experiments

Sherwin M. Beck
Space Station Freedom Office
NASA Langley Research Center
Hampton, Virginia

- OAST In-Space Technology Experiments Program
- Current In-Space Experiments
- OAST 1992 In-STEP Announcement of Opportunity
- OAST In-Space Development Process
In-Space Technology Experiments Program (In-STEP)

- Evolved from the NASA In-reach and Out-reach Programs
- Small in size and cost
- Proposals solicited as a group by Announcement of Opportunity from NASA, industry, universities
- Proposals solicited in technical areas of highest priority to OAST
- Selection based on rigorous technical and programmatic review (NASA, industry, and universities evaluators)

OAST Space Technology - In-space Experiments

Platforms
- 16 Experiments
- Mid-deck 0-G Dynamcis Experiment (MODE) flown on STS-48 Mission (MIT-SERC/LaRC)

Transportation
- 4 Experiments
- Tank Pressure Control Experiment (TPCE) flown on STS-43 Mission (Boeing/LeRC)

Science
- 6 Experiments

Planetary Surface
- 1 Experiment
In-Space Experiments

Platforms
- Emulsion Chamber Technology (ECT)
- Middeck Active Control Exp. (MACE)
- Joint Damping
- Middeck 0-G Dynamics Exp. (MODE)
- Middeck 0-G Dynamics Exp. Reflight
- Jitter Suppression
- Heat Pipe Performance (HPP)
- Liquid Motion
- Two-Phase Flow
- Risk Based Fire Safety
- Solar Array Module Plasma Interaction Exp. (SAMPLE)
- Thermal Energy Storage (TES)
- Modal Identification Experiment (MIE)
- Optical Properties Monitor
- Electrolysis
- Sodium Sulfur Battery

Transportation
- Tank Pressure Control Exp. (TPCE)
- Tank Pressure Control/Thermal Phenomenon (TPCE/TP)
- Vented Tank Resupply
- Acceleration Measurement

Science
- Investigation of Spacecraft Glow (GLOW)
- Cryo System Experiment
- Hydrogen Maser Clock
- Environmental Verification Exp. for the Explorer Platform (EVEEP)
- LIDAR In-space Technology Exp. (LITE)
- Inflatable Antenna
- Orbital Acceleration Research Exp. (OARE)
- Cryo-heat Pipe

Planetary Surface
- Permeable Membrane

In-STEP 1992 Announcement of Opportunity

- Technology Categories of Interest:
  1. Space materials, coatings, and environmental effects
  2. Cryogenic fluid handling
  3. Human support
  4. Space power
  5. In-space construction, repair, and maintenance
  6. Science sensors and sensor cooling
  7. Vibration isolation
  8. Space communications

- Key Points:
  - Approximately fifty Phase A proposals to be selected
  - New experiments ready for flight starting 1997
  - Use any suitable carrier—including Space Station Freedom
Experiment Selection Process

AO Released
Proposal Rec'd
Proposal Screening & Categorization
Technical/Management Review (by Category)
Costing/Management Review
Advisory Committee Presentation
Proposal Selection
Phase A Contract Award

Phase A: Feasibility

Review Process

Management Committee Evaluation
Selection Advisory Committee
Engineering Committee Evaluation
Selecting Official

Phase A Deliverables
- Project Objectives
- Feasibility Assessment
- 'Strawman' Technical Requirements
- ROM Cost & Schedule
- Phase B Plan, Including WBS

Selecting Official
- Selection of Instruments for Continuation in Phase B
Phase B: Project Definition

Review Process

Phase B Deliverables
- Conceptual Design
- Preliminary Instrument Requirements
- Estimated Cost & Schedule
- Preliminary Project Plan
- Phase 0 Safety Review*

Non-advocate Review

Instrument Review Board
- Approval of Instruments for Phase C/D Development

*or equivalent

Phase C/D: Project Implementation

Preliminary Design Deliverables
- Preliminary Design Drawings
- Instrument Specs
- Systems Analysis
- Final Project Plan
- Phase I Safety Documents*
- Preliminary Payload Integration Plan

Critical Design Deliverables
- Final Design Drawings
- Fabrication & Assembly Plan
- Systems Testing Plan
- Interface Control Document
- Phase II Safety Documents*
- Payload Integration Plan

Fabrication & Qual. Testing Deliverables
- Flight HW/SW Delivered
- Completed Qualification Testing
- Payload Integration Plan Annexes
- Phase III Safety Documents*

* or equivalent

* or equivalent
Phase E - Flight Operations and Technology Transfer

- Flight Operations
- Data Reduction/Analysis
- Conference Presentations
- Publications
ABSTRACT

The MIT Space Engineering Research Center is the principal investigator for a series of experiments which utilize the Shuttle Middeck as an engineering dynamics laboratory. The first, which flew on STS-48 in September 1991, was the Middeck O-gravity Dynamics Experiment (MODE). This experiment focused on the dynamics of a scaled deployable truss, similar to that of SSF, and of contained liquids in tanks. MODE will be reflown in the fall of 1993. In mid-1994, the Middeck Active Control Experiment (MACE) will examine the issues associated with predicting and verifying the closed loop behavior of a controlled structure in zero gravity. The paper will present experiment background, planning, operational experience, results and lessons learned from these experiments which are pertinent to SSF utilization.
PRECURSOR SSF UTILIZATION: 
THE MODE/MACE EXPERIMENTS

Edward F. Crawley  
Director, MIT SERC  
August 5, 1992

APPROACH

• Experimental background and philosophy  
• MODE STA experience  
• MODE FTA experience  
• MACE planning  
• Lessons learned
THE MODE FAMILY OF EXPERIMENTS

Fluid Test Article (FTA)
Coupled Non-Linear Dynamics of Fluids and Structures in Zero Gravity

Structural Test Article (STA)
Non-Linear Dynamics of Jointed Truss Structures in Zero Gravity

MACE Test Article
Influence of Gravity on the Active Control of a Multibody Platform

Flight #1:
Flight #2:

EXPERIMENTAL PHILOSOPHY

- Use the shuttle/station for engineering research (as opposed to demonstration or verification)
- Investigate (dynamics) phenomena which are influenced by gravity
- Use the Middeck Laboratory Module as a shirt sleeve lab environment with heavy reliance on crew interaction
- Use scaling laws to build model which capture the essential physics of the problem and yield results of practical value, at modest size and cost
MODE provides a reusable dynamics test facility which will be used on the first flight to test two rather different types of test articles.

**STA OBJECTIVES, REQUIREMENTS & APPROACH**

- **Engineering science objectives** are to characterize the fundamental changes in dynamics in 0-g due to absence of gravity on joints, to quantify the changes due to the absence of suspension and gravity load on members, and to obtain quantitative data for correlation with numerical models.

- **Requirements**
  - Truss structure containing elements of future space structures.
  - Nonlinear joints with variable pre-load to test nonlinear behavior in several gravity/joint pre-load conditions.
  - Reconfigurable truss with deployable and erectable bays.

- **Modelling approach**
  - Develop global linear model using FEM and modal test data.
  - Develop Force-State Map of non-linear sub-components.
  - Develop describing functions from Force-State Map.
  - Insert describing functions into global model and solve for forced response using Harmonic Balance Method.
  - Verify predictions with MODE flight and ground test results.
COMPARISON OF GROUND TO ORBITAL DATA
FOR THE BASELINE CONFIGURATION

NOTE: Torsion Mode Only. High Pre-Load.

TORSION MODE ALPHA LOOSE

\[ \text{Baseline Configuration -- PL1 -- Channel 6/Load Cell} \]

\[ \text{Space Data -- Channel 6/Load Cell} \]

\( o = \text{Low Force}; + = \text{Medium Force}; x = \text{High Force} \)
CONCLUSIONS OF ORBITAL TESTING

- Variation measured for erectable, deployable and articulated hardware as a function of force amplitude, joint preload and gravity loading
- Nonlinearities of the STA are more apparent in 0-gravity, especially the alpha loose, which loses resonant behavior
- Modes generally soften with increasing force, but increase in damping is significantly more pronounced
- Changes in frequency between earth and space are generally within the variance of ground testing for the baseline, but outside the variance for the alpha and L configurations.
- Changes in damping are well outside the variance of ground testing

FTA OBJECTIVES, REQUIREMENTS AND APPROACH

- Engineering science objective is to characterize fundamental 0-g slosh behavior and obtain quantitative data on slosh force and spacecraft response for correlation of numerical model.
- Requirements
  - Scaled tank
  - Properly modelled fluid
  - Simulation of coupled spacecraft mode
  - Harmonic excitation
  - Measurement of slosh force
- Modelling approach
  - Find fluid flow potential and free surface motion solutions.
  - Express kinetic and potential energies in terms of generalized coordinates.
  - Derive governing differential equations by applying Lagrange's Principle.
  - Solve nonlinear equations subject to harmonic excitation.
  - Verify predictions with MODE flight and ground test results.
Uncoupled Test with Distilled Water as Test Fluid in a 3.1 cm Flat Bottom Cylindrical Tank.
Planar Slosh Force.

Uncoupled Test with Distilled Water as Test Fluid in a 3.1 cm Flat Bottom Cylindrical Tank.
Non-planar Slosh Force.
SUMMARY AND CONCLUSIONS

Space Experiments:
- More benign nonlinear behavior in space than observed on earth
- Modal damping ratios and frequencies significantly different from earth tests
- Demonstrated the ability to investigate fluid slosh in micro-gravity

Analytical Model
- Model more accurate for one-gravity conditions
- Nonlinear solution required that can find "all" the solutions
- Accurate prediction of slosh damping ratios a pre-requisite for an accurate prediction

Future
- Improve nonlinear solution technique
- More space experiments required to investigate effects of contact angle hysteresis, contact angles and dissipation rates.

MODE RESOURCE SUMMARY

Mode pushed the current Middeck capabilities:

- 115 Watts
- 3 1/2 lockers
- 60 lbs in a single locker
- 16 hours of on orbit testing
- about 25% of Middeck volume during STA testing
MACE SCIENCE OBJECTIVE

To develop a well verified set of Control Structure Interaction - Controlled Structures Technology (CSI/CST) methods and approaches that will allow designers of future CST spacecraft, which cannot be dynamically tested on the ground in a sufficiently realistic zero-gravity simulation, to have confidence in the eventual orbital performance of such spacecraft.

THE MACE APPROACH

• Select a test article of interest to NASA, which has near-term mission relevancy, is CSI challenging, and is sensitive to gravity perturbations.
• Dynamically scale the test article to fit in middeck in order to integrate at low cost.
• Become a pathfinder for CSI Qualification scenario:
  - Develop analytical models to incorporate the predicted gravity effects. This will lead to development of analytical CSI tools for use by future spacecraft.
  - Perform an extensive ground test program using state-of-the-art suspension systems to identify ground test limitations.
  - Perform a flight test with controllers derived from ground testing/modeling as well as from on-orbit testing.
• Transfer technology to the government/industrial sector
• Educate the next generation of engineers with a challenging, scientifically relevant project.
THE MIDDECK ACTIVE CONTROL EXPERIMENT (MACE)

- Substantial commonality of ESM hardware/software
- Significant savings in integration/certification process.

MULTIBODY PLATFORM - CONFIGURATION #1
ON-ORBIT OPERATIONS SUMMARY

- Operations require one crew member for three eight-hour days.
- First day operations include:
  - test article assembly and electronics check-out;
  - open-loop system identification;
  - implementation of pre-programmed control protocols;
  - system ID data reduction in preparation for downlink;
  - downlink of system identification data;
  - disassembly and storage of hardware.
- Second day operations include:
  - test article assembly and electronics check-out;
  - implementation of pre-programmed control protocols;
  - disassembly and storage of hardware.
- Third day operations include:
  - test article assembly and electronics check-out;
  - uplink of system identification data-based controllers;
  - implementation of uplinked control protocols;
  - disassembly and storage of hardware.

RESOURCE SUMMARY

<table>
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<tr>
<th>RESOURCE</th>
<th>ACTUAL</th>
<th>TARGET</th>
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<tr>
<td>Mass</td>
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<tr>
<td>ESM</td>
<td>57.3 lbs</td>
<td>59.0 lbs</td>
<td>68 lbs</td>
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<tr>
<td>Test Article</td>
<td>86 lbs</td>
<td>100 lbs</td>
<td>162 lbs</td>
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<tr>
<td>Volume</td>
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<tr>
<td>Stowed</td>
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<tr>
<td>Operational</td>
<td>70 ft³</td>
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<td>Operations</td>
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<td></td>
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<tr>
<td>Crew Members</td>
<td>1</td>
<td>1</td>
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<td>Crew Time</td>
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<tr>
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MODE/MACE LESSONS LEARNED

- Low cost experiments happen
- Integration is an art, not a science
- PI should be responsible for payload mission success, integrating center
- Crew can be versatile contributor, if well prepared
- Investigator team must be prepared for mission operations, and their limitations
- Hardware shortcuts are penny-wise and pound foolish
- Scaling laws can be exploited to do small/low cost research experiments
- Flight experiments are fun, but take a significant fraction of a career
ABSTRACT

Space Station Freedom presents a unique opportunity for technology developers to conduct research in the space environment. Research can be conducted in the pressurized volume of the Space Station's laboratories or attached to the Space Station truss in the vacuum of space. Technology developers, represented by the Office of Aeronautics and Space Technology (OAST), will have 12% of the available Space Station resources (volume, power, data, crew, etc.) to use for their research.

Most technologies can benefit from research on Space Station Freedom and all these technologies are represented in the OAST proposed traffic model. This traffic model consists of experiments that have been proposed by technology developers but not necessarily selected for flight. Experiments to be flown in space will be selected through an Announcement of Opportunity (A.O.) process. The A.O. is expected to be released in August, 1992. Experiments will generally fall into one of the 3 following categories: (1) Individual technology experiments, (2) Instrumented Space Station, and (3) Guest investigator program. The individual technology experiments are those that do not instrument the Station nor directly relate to the development of technologies for evolution of Space Station or development of advanced space platforms. The Instrumented Space Station category is similar to the Orbiter Experiments Program and allows the technology developer to instrument subsystems on the Station or develop instrumentation packages that measure products or processes of the Station for the advancement of space platform technologies. The guest investigator program allows the user to request data from Space Station or other experiments for independent research.

When developing an experiment, a developer should consider all the resources and infrastructure that Space Station Freedom can provide and take advantage of these to the maximum extent possible. Things like environment, accommodations, carriers and integration should all be taken into account. In developing experiments at Langley Research Center an iterative approach is proving useful. This approach uses Space Station utilization and subsystem experts to advise and critique experiment designs to take advantage of everything Station has to offer. Also, solid object modeling and animation computer tools are used to fully visualize the experiment and its processes. This process is very useful for attached payloads and allows problems to be detected early in the experiment design phase.
UTILIZATION OF SPACE STATION FREEDOM FOR TECHNOLOGY RESEARCH

OVERVIEW
ATTACHED PAYLOADS
DESIGN CONSIDERATIONS

Presented To:
Space Station Freedom Utilization Conference

Presented by:
Don E. Avery
Manager, Technology Experiments
Space Station Utilization Office

August 5, 1992
ALLOCATION OF SSF RESOURCES

NASA ALLOCATIONS

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<th>Component</th>
<th>Allocation</th>
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<td>U.S. LAB</td>
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<tr>
<td>EXTERNAL TRUSS</td>
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<tr>
<td>ESA LAB</td>
<td>47%</td>
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<tr>
<td>JEM LAB &amp; EXPOSURE FAC.</td>
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OAST SUB-ALLOCATION
12% OF NASA ALLOCATION

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<th>Resource</th>
<th>Allocation</th>
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<td>ONBOARD DATA STORAGE</td>
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<tr>
<td>UP/DOWN VOLUME</td>
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<tr>
<td>DOWN LINK</td>
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<td>POWER</td>
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<td>CREW TIME</td>
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IN-SPACE TECHNOLOGY EXPERIMENT NEEDS

ENVIRONMENT

PRESSURIZED VOLUME
UNPRESSURIZED SITES

RESOURCES

POWER
CREW
DATA
SPACE STATION FREEDOM

SSF CAN SUPPLY ALL TECHNOLOGY EXPERIMENT REQUIREMENTS
TECHNOLOGIES TO BENEFIT FROM SSF

- MATERIAL EXPOSURE RESEARCH
- STRUCTURAL DYNAMICS
- SPACE OPERATIONS
- SPACE CONSTRUCTION
- LIFE SUPPORT SYSTEMS
- ELECTRONICS
- FLUIDS
- ROBOTICS
- POWER
- THERMAL

TECHNOLOGIES REPRESENTED IN CURRENT OAST TRAFFIC MODEL

PROPOSED TRAFFIC MODEL FOR SSF
(FOR PLANNING PURPOSES)

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<th>Attached P/Ls*</th>
<th>Pressurized P/Ls*</th>
<th>LSE</th>
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<td>1997</td>
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<th>Pressurized P/Ls*</th>
<th>LSE</th>
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<td>1999</td>
<td>Cryo-Tank Servicing Exp, LDR Structural Exp, Liquid Stream Tech, Test Bed</td>
<td>Microbiological Monitor for S/C Regenerative Life Support, T-1</td>
<td>Robot for Laboratory, Quantized Vortex Str. He, Two-Phase Fluid Behavior</td>
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*UP PAYLOADS ONLY
**TECHNOLOGY PAYLOAD CATEGORIES**

- **INDIVIDUAL TECHNOLOGY PAYLOADS**
  - SPACECRAFT MATERIALS AND COATINGS
  - ADVANCED SENSOR DEVELOPMENT
  - TRANSIENT UPSET PHENOMENON IN VLSIC

- **INSTRUMENTED SPACE STATION**
  - OEX TYPE EXPERIMENTS
  - INSTRUMENT STATION SUBSYSTEM
    - STRUCTURES- MIE
    - ENVIRONMENTAL
    - THERMAL
    - DATA

- **GUEST INVESTIGATOR PROGRAM**
  - USE DATA FROM EXISTING INSTRUMENTS
    - MIE
    - STATION SUBSYSTEM INSTRUMENTS

**TECHNOLOGY PAYLOAD DESIGN CONSIDERATIONS**

- **ENVIRONMENT**
  - PRESSURIZED PAYLOADS
  - ATTACHED PAYLOADS

- **PAYLOAD ACCOMMODATIONS**
  - RESOURCES AVAILABLE
    - POWER, DATA, CREW, ETC.
  - REAL ESTATE
    - RACKS, ATTACHMENT SITES, PALLETS

- **CARRIER**
  - TRANSPORTATION
  - PLM/ULC
  - RACK/DRAWER/ULC

- **INTEGRATION**
  - ONTO CARRIERS
  - ONTO STATION
PAYLOAD CARRIER SYSTEMS

PRESSURIZED PAYLOADS

ATTACHED PAYLOADS

MINI PAYLOAD LOGISTICS MODULE

INTERNATIONAL STANDARD PAYLOAD RACK

TRANSPORTATION

ATTACHED PAYLOADS

EXAMPLE

PAYLOAD SITES:

STARBOARD 1 - Available May 1997
STARBOARD 2 - Available May 1997
PORT 1 - Available August 1997
PORT 2 - Available August 1997

PAYLOAD VOL. ENVELOPE:

DIFFERENT AT EACH SITE

DATA:

1553 LOCAL BUS (MAX THROUGHPUT 700 kbps MINUS OVERHEAD)

EVA:

INSTALL PROPULSION MODULE ADAPTOR SYSTEM

THERMAL:

NONE

CARRIER:

UNPRESSURIZED LOGISTIC CARRIER OF SOME DESIGN

STATION INTEGRATION:

PMAS PAYLOAD PALLET ROBOTIC INSTALLATION
Space Station Freedom
WP-2 Pre-Integrated Truss
Attached Payload Accommodations

ATTACHED PAYLOAD OPERATIONAL ENVELOPE
SITE - STARBOARD 1

- S1/M1 Bulkhead
- Ku-Band Antenna (hidden)
- Radiator Sweep

Accommodations:
- Power: 2.5 kW each site, 6 kW aggregate
- Data: 1536 logic (1024 bits down / 512 bits up)
- Use of control station attachment mechanism (modified propulsion module assembly structure)
- Panels and payloads are representative only.
SOLID OBJECT MODELING

- GIVES VISUAL PERSPECTIVE OF CARRIER AND EXPERIMENT

- ALLOWS OBSERVATION OF PROBLEMS EARLY IN DESIGN
  - S-BAND ANTENNA CLOSE TO EXPERIMENT
  - U.S. LAB MAY VENT ONTO EXPERIMENT
  - VIEWING
  - SHADOWS
  - ETC.
ANIMATION

- ANIMATION ALLOWS FULL VISUALIZATION OF SCENE
  - WAVEFRONT USED AS ANIMATION TOOL
  - WAVEFRONT USES 3D OBJECT
  - 2D IMAGES CAN BE RENDERED FROM 3D OBJECTS FOR STILLS OR VIDEO

- ALLOWS OBSERVATION OF PROBLEMS EARLY IN DESIGN PROCESS
  - MOTION RESTRICTIONS BECAUSE OF UNKNOWN OBSTACLES
  - KEEP OUT ENVELOPES
  - MOVEMENT RESTRICTIONS OF ROBOTIC ARMS
  - COMPLICATED MOVEMENTS SHOWN VISUALLY INSTEAD OF EXPLAINED
OAST ANNOUNCEMENT OF OPPORTUNITY
SPACE EXPERIMENTS PROGRAM

• PURPOSE
  TO SOLICIT PROPOSALS FOR EXPERIMENTS IN THE TECHNOLOGY CATEGORIES
  - SPACE MATERIALS, COATINGS, AND ENVIRONMENTAL EFFECTS
  - CRYOGENIC FLUID HANDLING
  - HUMAN SUPPORT
  - SPACE POWER
  - IN-SPACE CONSTRUCTION, REPAIR, AND MAINTENANCE
  - SCIENCE SENSORS AND SENSOR COOLING
  - VIBRATION ISOLATION
  - SPACE COMMUNICATION

• APPROACH
  - APPROXIMATELY FIFTY PROPOSALS SELECTED BY RIGOROUS REVIEW PROCESS FOR PHASE A
  - DOWN-SELECTION TO PHASE B, LEADING TO NON-ADVOCATE REVIEW
  - NEW EXPERIMENTS READY FOR FLIGHT STARTING 1997
  - ANY SUITABLE CARRIER UTILIZED, INCLUDING SSF, SHUTTLE, ELV

• STATUS
  - EXPECTED RELEASE IN AUGUST
MODAL IDENTIFICATION EXPERIMENT

Presented by Raymond G. Kvaternik
Spacecraft Dynamics Branch
NASA Langley Research Center

ABSTRACT

The Modal Identification Experiment (MIE) is a proposed on-orbit experiment being developed by NASA's Office of Aeronautics and Space Technology wherein a series of vibration measurements would be made on various configurations of Space Station Freedom (SSF) during its on-orbit assembly phase. The experiment is to be conducted in conjunction with station reboost operations and consists of measuring the dynamic responses of the spacecraft produced by station-based attitude control system and reboost thrusters, recording and transmitting the data, and processing the data on the ground to identify the natural frequencies, damping factors, and shapes of significant vibratory modes. The experiment would likely be a part of the Space Station on-orbit verification.

Basic research objectives of MIE are to evaluate and improve methods for analytically modeling large space structures, to develop techniques for performing in-space modal testing, and to validate candidate techniques for in-space modal identification. From an engineering point of view, MIE will provide the first opportunity to obtain vibration data for the fully-assembled structure because SSF is too large and too flexible to be tested as a single unit on the ground. Such full-system data is essential for validating the analytical model of SSF which would be used in any engineering efforts associated with structural or control system changes that might be made to the station as missions and uses evolve over time.

Extensive analytical simulations of on-orbit tests, as well exploratory laboratory simulations using small-scale models, have been conducted in-house and under contract to develop a measurement plan and evaluate its potential performance. In particular, performance trade and parametric studies conducted as part of these simulations were used to resolve issues related to the number and location of the measurements, the type of excitation, data acquisition and data processing, effects of noise and nonlinearities, selection of target vibration modes, and the appropriate type of data analysis scheme.

The purpose of this talk is to provide an executive-summary-type overview of the modal identification experiment which has emerged from the conceptual design studies conducted to-date. Emphasis throughout is on those aspects of the experiment which should be of interest to those attending the subject utilization conference. The presentation begins with some preparatory remarks to provide background and motivation for the experiment, describe the experiment in general terms, and cite the specific technical objectives. This is followed by a summary of the major results of the conceptual design studies conducted to define the baseline experiment. The baseline experiment which has resulted from the studies is then described.
MODAL IDENTIFICATION EXPERIMENT

Raymond G. Kvaternik
NASA Langley Research Center
Hampton, Virginia

Space Station Freedom Utilization Conference
Huntsville, Alabama
August 3-6, 1992

OUTLINE

• Introductory Remarks

• Experiment Definition Studies

• Baseline Experiment Design

• Summary and Concluding Remarks
INTRODUCTORY REMARKS

MOTIVATION

- Dynamic characteristics of spacecraft traditionally verified by ground vibration tests

- Emerging space structures (such as Space Station Freedom) too large/flexible to test as complete systems on ground

- Complete reliance on math models to verify dynamic behavior

- Math models must be validated to establish accuracy

- Vibration mode shapes for fully-assembled structure essential for validating/updating dynamic models

- Required data can only be obtained on-orbit
BACKGROUN

• Modal Identification Experiment (MIE) utilizing Space Station Freedom (SSF) proposed in 1984

• Element of NASA's space technology program
  • Sponsor is Office of Aeronautics and Space Technology
  • Object is in-space research and technology

• Not element of Space Station program

ESSENCE OF PROPOSED EXPERIMENT

• Collect vibration measurements on various configurations of SSF during its on-orbit assembly phase

• Conduct experiment in conjunction with station reboost operations

• Key Steps:
  • Excite structure
  • Measure dynamic responses
  • Record and transmit data
  • Apply system identification techniques to data

• Identify significant vibratory modes
ON-ORBIT ASSEMBLY OF SPACE STATION PERMITS UNIQUE RESEARCH OPPORTUNITY

SPECIFIC TECHNICAL OBJECTIVES

- Engineering
  - Data essential for verifying dynamic math models of integrated system
  - Enhanced model for changes/growth studies

- Research
  - Technology for predicting dynamics of large space structures
  - Techniques for performing on-orbit modal testing
  - Spacecraft scale model ground vibration test technology
  - Techniques for in-space system identification
  - Improved dynamics modeling techniques
EXPERIMENT DEFINITION STUDIES

MAJOR PARTICIPANTS

- McDonnell Douglas Space Systems Company
  - Phase A Study - Determine feasibility
  - Phase B Study - Conceptual design definition
  - Delta Phase B Study - Assess impact of new SS design

- Structural Dynamics Research Corporation
  - Develop simulation and evaluation methods

- University of Cincinnati
  - Modal parameter estimation techniques

- NASA Langley Research Center
  - Analytical simulation
  - Dynamic scale model test simulation
SCHEDULE FOR STUDIES

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LABORATORY SIMULATION USING SCALE MODELS

- MB-2 Configuration
- Response History
  - Acceleration vs. Time
- Modal Identification Algorithm
- Modal Data:
  - Frequencies
  - Mode Shapes
  - Damping Ratios
- Experiment Design Performance Evaluation

- Simulated On-Orbit Excitation
- Force vs. Time
- Shaker
- Feedback Control
- Load Cell

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MIE SIMULATIONS USING GENERIC MODEL

MIE simulations correlated well with modal test results

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MIE SIMULATIONS USING HYBRID MODEL

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BASELINE EXPERIMENT DESIGN

FINITE ELEMENT MODELS

MTC+ Configuration
(SC-7)

PMC Configuration
(SC-17)

Degrees of Freedom in Preliminary Design Model

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SELECTION OF IMPORTANT MODES

- Emphasis on global structural modes of integrated structure with frequencies below 5 Hz
- Several global mode indicators used in selection
- Resultant mode set includes truss bending and torsion modes, as well as solar array and radiator modes
- Frequencies of all modes below 2 Hz
- For MTC+: 13 Modes (0.53 - 2.09 Hz)
  For PMC: 18 Modes (0.17 - 1.32 Hz)

MIE RANDOM EXCITATION PATTERNS

Typical Excitation Patterns of Thrusters
BASELINE MEASUREMENT SET FOR MIE
Instrumentation Locations

187 accelerometers proposed

BASELINE SIMULATIONS

- Intended to demonstrate adequacy of baseline experiment design to identify important modes

- Simulated experimental data contained expected types and levels of data acquisition errors

- Eigensystem Realization Algorithm (ERA) used to extract modal parameters from time-domain free-decay responses

- Modal characteristics of all target modes for MTC+ identified

- All target modes except the two with highest frequencies identified for PMC
SUMMARY AND CONCLUDING REMARKS

• Modal Identification Experiment utilizing Space Station Freedom feasible
• Conceptual design of baseline experiment completed
• Simulations of experiment demonstrated adequacy of design to identify selected important modes
• If implemented, experiment would yield data of both engineering and research value
• Accelerometer complement proposed by SSFP as part of on-orbit verification instrumentation suite does not meet all MIE requirements
• Doubtful if additional sensors will be authorized
• Need to make best use of whatever number of accelerometers will be on Space Station
SELECTED OAST/OSSA SPACE EXPERIMENT ACTIVITIES IN
SUPPORT OF SPACE STATION FREEDOM

Presented by Richard DeLombard
In-Space Technology Experiments
NASA Lewis Research Center

ABSTRACT

The Space Experiments Division at NASA Lewis Research Center is developing technology and science space experiments for the Office of Aeronautics and Space Technology (OAST) and the Office of Space Sciences and Applications (OSSA). Selected precursor experiments and technology development activities supporting the Space Station Freedom (SSF) are presented.

The Tank Pressure Control Experiment (TPCE) is an OAST-funded cryogenic fluid dynamics experiment, the objective of which is to determine the effectiveness of jet mixing as a means of equilibrating fluid temperatures and controlling tank pressures, thereby permitting the design of lighter cryogenic tanks. The information from experiments such as this will be utilized in the design and operation of on board cryogenic storage for programs such as SSF.

The Thermal Energy Storage Flight Project (TES) is an OAST-funded thermal management experiment involving phase change materials for thermal energy storage. The objective of this project is to develop and fly in-space experiments to characterize void shape and location in phase change materials used in a thermal energy storage configuration representative of an advanced solar dynamic system design. The information from experiments such as this will be utilized in the design of future solar dynamic power systems.

The Solar Array Module Plasma Interaction Experiment (SAMPIE) is an OAST-funded experiment to determine the environmental effects of the low earth orbit (LEO) space plasma environment on state-of-the-art solar cell modules biased to high potentials relative to the plasma. Future spacecraft designs and structures will push the operating limits of solar cell arrays and other high voltage systems. SAMPIE will provide key information necessary for optimum module design and construction.

The Vibration Isolation Technology (VIT) Advanced Technology Development effort is funded by OSSA to provide technology necessary to maintain a stable microgravity environment for sensitive payloads on board spacecraft. The proof of concept will be demonstrated by laboratory tests and in low-gravity aircraft flights. VIT is expected to be utilized by many SSF microgravity science payloads.

The Space Acceleration Measurement System (SAMS) is an OSSA-funded instrument to measure the microgravity acceleration environment for OSSA payloads on the shuttle and SSF.
AGENDA

- INTRODUCTION
- TANK PRESSURE CONTROL EXPERIMENT
- THERMAL ENERGY STORAGE
- SOLAR ARRAY MODULE PLASMA INTERACTION EXPERIMENT
- VIBRATION ISOLATION TECHNOLOGY
- SPACE ACCELERATION MEASUREMENT SYSTEM
- CONCLUDING REMARKS
INTRODUCTION

• THE LeRC SPACE EXPERIMENTS DIVISION SUPPORTS SSF THROUGH:

OAST/SPACE EXPERIMENTS OFFICE-FUNDED
IN-SPACE TECHNOLOGY EXPERIMENTS PROGRAM

OSSA/MSAD-FUNDED
MICROGRAVITY SCIENCE EXPERIMENTS
ADVANCED TECHNOLOGY DEVELOPMENT ACTIVITIES

• THIS PRESENTATION WILL COVER THESE SELECTED TOPICS:

OAST:
- TANK PRESSURE CONTROL EXPERIMENT
- THERMAL ENERGY STORAGE FLIGHT PROJECT
- SOLAR ARRAY MODULE PLASMA INTERACTION EXPERIMENT

OSSA:
- VIBRATION ISOLATION TECHNOLOGY
- SPACE ACCELERATION MEASUREMENT SYSTEM FOR SSF

SSF Utilization Conference 8/3-6/92

TANK PRESSURE CONTROL EXPERIMENT

TECHNOLOGY NEED:

• CONTROL OF TANK PRESSURE FOR CRYOGENIC FLUID MANAGEMENT

OBJECTIVES:

• CHARACTERIZE FLUID DYNAMICS OF JET-INDUCED MIXING

• ESTABLISH LOW-GRAVITY MIXING TIMES TO EQUILIBRATE PRESSURE & TEMPERATURE

SSF Utilization Conference 8/3-6/92
TANK PRESSURE CONTROL EXPERIMENT

APPROACH:
• USE JET-INDUCED FLUID MIXING AS A MEANS OF CONTROLLING PRESSURE OF FREON 113 IN LOW-GRAVITY
• IMPLEMENT AS GAS-CAN EXPERIMENT WITH CONTRACT TO BOEING (OAST-FUNDED)

STATUS:
• EXPERIMENT FLEW ON STS-43 IN AUGUST 1991
• POSITIVE RESULTS OBTAINED
• RE-FLIGHT PLANNED FOR STS-52 IN OCTOBER 1992
  - FOCUS ON SELF-PRESSURIZATION AND POOL BOILING AT LOW HEAT FLUXES
  - EXTEND MIXING DATA BASE TO LOWER FLOWS

THERMAL ENERGY STORAGE

TECHNOLOGY NEED:
• MELT/FREEZE BEHAVIOR DATA BASE FOR PHASE CHANGE MATERIALS IN LONG DURATION LOW-GRAVITY ENVIRONMENT

OBJECTIVES:
• CHARACTERIZE MELT/FREEZE BEHAVIOR OF PHASE CHANGE MATERIALS IN LOW-GRAVITY
• PROVIDE EXPERIMENTAL DATA TO VERIFY ANALYTICAL MODELS NOW UNDER DEVELOPMENT
THERMAL ENERGY STORAGE

APPROACH:

• THERMALLY CYCLE TWO DIFFERENT PHASE CHANGE MATERIALS
  - LITHIUM FLUORIDE
  - FLUORIDE EUTECTIC

• IMPLEMENT IN-HOUSE AT NASA LEWIS AS GET-AWAY-SPECIAL PAYLOADS (OAST-FUNDED)

• FLY TWO EXPERIMENTS EACH IN 1994 AND 1996

SOLAR ARRAY MODULE PLASMA INTERACTION EXPERIMENT

TECHNOLOGY NEED:

• DETERMINE THE EFFECTS OF LEO SPACE PLASMA ON SOLAR CELL MODULES

APPROACH:

• EXPOSE SEVERAL TYPES OF MODULES TO SPACE PLASMA OVER A RANGE OF POTENTIALS

• IMPLEMENT IN-HOUSE AT NASA LEWIS (OAST-FUNDED)

• FLY AS CARGO BAY EXPERIMENT IN 1994

OBJECTIVES:

• DETERMINE ARCING_THRESHOLDS, RATES AND STRENGTHS

• DETERMINE PLASMA CURRENT COLLECTION CHARACTERISTICS

• MEASURE PARAMETERS FOR DATA ANALYSIS

• VALIDATION OF MODELS
SOLAR ARRAY MODULE PLASMA INTERACTION EXPERIMENT

STATUS:
• EXPERIMENT UNDER DEVELOPMENT FOR OAST-2 MISSION

• SOLAR MODULES WILL INCLUDE:
  - SPACE STATION FREEDOM CELLS
  - ADVANCED PHOTOVOLTAIC SOLAR ARRAY CELLS
  - STANDARD SILICON CELLS (REFERENCE)

VIBRATION ISOLATION TECHNOLOGY

TECHNOLOGY NEED/OBJECTIVE

PROVIDE THE REQUIRED TECHNOLOGY TO MAINTAIN A STABLE MICROGRAVITY ENVIRONMENT FOR SENSITIVE PAYLOADS OVER THE FREQUENCY RANGE APPLICABLE TO DISTURBANCES PRESENT IN SPACECRAFT.

APPROACH

• DEFINE TECHNOLOGY REQUIREMENTS AND ASCERTAIN LIMITS OF CURRENT STATE OF THE ART METHODS.

• DEVELOP TECHNOLOGY VIA A GROUND BASED PROGRAM THAT MEETS THE REQUIREMENTS; EXPAND THE STATE OF THE ART.

• DEMONSTRATE THE PROOF OF CONCEPT IN A LABORATORY ENVIRONMENT AND IN LOW GRAVITY AIRCRAFT FLIGHTS.
VIBRATION ISOLATION TECHNOLOGY

STATUS

- ACTIVELY CONTROLLED, MAGNETIC ISOLATION SYSTEM DEVELOPED IN LABORATORY,
  - SIX DEGREES OF FREEDOM
  - INERTIAL AND POSITION FEEDBACK
  - ISOLATION DOWN TO MICROGRAVITY LEVELS AT 0.1 HZ

- PROOF OF CONCEPT VERIFIED IN LOW GRAVITY PARABOLIC FLIGHTS DOWN TO 1 HZ
  - FREQUENCY LIMITED BY LOW GRAVITY TIME AVAILABLE.
  - TWELVE FLIGHTS WITH 72 TRAJECTORIES FLOWN.
  - PERFORMANCE OF ISOLATION SYSTEM PREDICTABLE.
  - ISOLATION ACHIEVED DOWN TO NOISE FLOOR OF SYSTEM.

- LOW FREQUENCY VERIFICATION (< 0.1 HZ) MUST BE DONE THROUGH FLIGHT EXPERIMENT.

SPACE ACCELERATION MEASUREMENT SYSTEM FOR SPACE STATION FREEDOM

PROGRAMMATIC NEED:

- MEASURE THE MICROGRAVITY ENVIRONMENT FOR OSSA SCIENCE PAYLOADS ON SPACE STATION FREEDOM

APPROACH:

- REMOTE SENSORS LOCATED WITHIN EXPERIMENTS
- DATA RECORDED ON-BOARD AND/OR DOWN-LINKED TO GROUND CONTROL CENTER
- IMPLEMENTED IN-HOUSE AT NASA LEWIS (OSSA-FUNDED)

OBJECTIVE:

- SUPPORT OSSA PRINCIPAL INVESTIGATORS WITH MICROGRAVITY ACCELERATION DATA
SPACE ACCELERATION MEASUREMENT SYSTEM FOR SPACE STATION FREEDOM

STATUS:

- SAMS UNITS CURRENTLY BEING FLOWN WITH OSSA SCIENCE EXPERIMENTS ON SHUTTLE MISSIONS
- NEW & IMPROVED INSTRUMENT BEING DEVELOPED FOR U.S. LABORATORY MODULE
- TYPICAL SPACE STATION FREEDOM EXPERIMENTS SUPPORTED:
  - SPACE STATION FURNACE FACILITY
  - COMBUSTION EXPERIMENTS MODULE
  - FLUID EXPERIMENTS MODULE

CONCLUDING REMARKS

- EXISTING OAST EXPERIMENTS ARE VIEWED AS PRECURSOR EXPERIMENTS FOR SPACE STATION FREEDOM
- VIBRATION ISOLATION TECHNOLOGY REQUIRES VALIDATION TO SUPPORT FUTURE FLUID PHYSICS & OTHER MICROGRAVITY SPACE EXPERIMENTS
- SPACE ACCELERATION MEASUREMENT SYSTEM WILL CONTINUE TO SUPPORT OSSA / MSAD EXPERIMENTS
ABSTRACT

The 5.8-year exposure data from the Long Duration Experiment Facility (LDEF) has demonstrated the benefits of long-term exposure in low Earth orbit (LEO) for understanding the behavior of spacecraft materials and coatings for use in extended space missions. The Space Station Freedom represents the next large area spacecraft available in NASA planned missions for obtaining this long-term space exposure data.

The advantages of using the Space Station Freedom for these studies are presented. Discrepancies between short-term flight exposure result from Shuttle Orbiter experiments and the long-term LDEF results are shown. The major objectives and benefits of conducting materials and coatings experiments on Space Station Freedom are emphasized.
CONCLUSIONS FROM LDEF MATERIALS ANALYSIS

- Atomic oxygen is major near-Earth orbital environmental factor leading to mechanical/optical property changes in materials
- All polymeric materials exhibit some mass loss from AO exposure
- Uncoated resin matrix composites display resin and fiber loss and deterioration in mechanical properties proportional to thickness loss
- Molecular structure of surviving polymeric resin and films unchanged
- Thin metallic coatings can prevent AO damage
LESSONS LEARNED FROM LDEF EXPERIMENTS

- Leading edge surfaces are dominated by AO effects while surfaces greater than 110° are dominated by contamination and UV effects
  - Different exposure surfaces are needed for meaningful flight experiments

- Cannot confidently extrapolate long-term space effects on materials from short-term flight experiments like EOIM
  - Long-term exposure data are needed

- Confirmed suspected instability of polymeric materials to LEO atomic oxygen exposure
  - More data needed to support materials development programs for AO resistant materials

- More choices of protective coatings are needed to prevent AO damage to materials
  - Choices are very limited for large parts

PASSIVE MATERIALS AND COATINGS EXPERIMENT

Why Space Station Freedom?

- After initial development phase, Space Station Freedom presents a stable platform for materials exposures and acquisition of environmental data
- Only spacecraft available for long-term (>1 year) materials and coatings exposure
- Large areas available for exposure of materials and coatings
- Power and data storage available for use with active experiments
- Materials exposed real-time in same LEO environment where they are being used
- Ready access for material exchange and return of exposed materials to Earth for laboratory testing
MATERIALS FLIGHT EXPERIMENTS ON SSF

Objectives

- Establish a technology database for long-term effects of LEO environment on spacecraft materials and coatings

- Database will support:
  - Development of ground-based technology for accelerated long-duration environmental effects testing
  - Development of new materials and coatings with high resistance to atomic oxygen, solar UV, and particulate radiation
  - Development of Multiparameter Laboratory testing techniques. Example: AO + UV + vacuum + temperature cycling in one system
  - Alternate materials for advanced retro-fit or repair of Freedom

MATERIALS FLIGHT EXPERIMENTS ON SSF

Justification

- Multi-environment simulation of atomic oxygen, UV, vacuum, thermal cycling, micrometeoroid, debris, and particulate radiation is not technically feasible in ground-based laboratory testing

- Cannot confidently extrapolate long-term space effects from short-term accelerated flight data
  - FEP Teflon AO erosion 6 times greater on LDEF than predicted from EOIM-2 flight results
  - Epoxy matrix composites AO erosion on LDEF was 1/2 of erosion predicted from EOIM-2 flight results

- Long-term flight database needed to develop ground-based accelerated testing technology
  - LDEF provides only flight data available on materials exposed for 5-year mission lifetime
MATERIALS FLIGHT EXPERIMENTS ON SSF

Benefits

- Assist in development of new materials for 21st century
- Provide data for improved laboratory simulation of space environment
- Provide data to correlate highly accelerated testing of materials with real-time effects
- Verification of ground-based lifetime prediction
- Additional utilization of Space Station Freedom as a testing/exposure laboratory in space

SUMMARY

- LDEF providing substantial long-term LEO exposure data on space environmental effects on materials
- LDEF underscore the need for long-term flight data
- Space Station Freedom only spacecraft manifested for long-term (>5 years) operation
- Materials experiment proposed for beneficial utilization of Space Station Freedom
LONG DURATION SPACE MATERIALS EXPOSURE (LDSE)

Presented by David Allen and Robert Schmidt
Center on Materials for Space Structures
Case Western Reserve University

ABSTRACT

The Center on Materials for Space Structures (CMSS) at Case Western Reserve University is one of seventeen Commercial Centers for the Development of Space. It was founded to: 1) Produce and evaluate materials for space structures, 2) Develop passive and active facilities for materials exposure and analysis in space, and 3) Develop improved material systems for space structures.

A major active facility for materials exposure is proposed to be mounted on the exterior truss of the Space Station Freedom (SSF). This Long Duration Space Materials Exposure (LDSE) experiment will be an approximately 6 1/2 ft x 4 ft panel facing into the velocity vector (RAM) to provide long term exposure (up to 30 years) to atomic oxygen, UV, micrometeorites, and other low earth orbit effects. It can expose large or small active (instrumented) or passive samples. These samples may be mounted in a removable Materials Flight Experiment (MFLEX) carrier which may be periodically brought into the SSF for examination by CMSS’s other SSF facility, the Space Materials Evaluation Facility (SMEF) which will contain a Scanning Electron Microscope, a Variable Angle & Scanning Ellipsometer, a Fourier Transform Infrared Spectrometer, and other analysis equipment. These facilities will allow commercial firms to test their materials in space and promptly obtain information on their materials survivability in the LEO environment.
LONG DURATION SPACE MATERIALS EXPOSURE (LDSE)

CENTER ON MATERIALS FOR SPACE STRUCTURES
CASE WESTERN RESERVE UNIVERSITY

AUGUST 5, 1992

The Center on Materials for Space Structures

A Center for the Commercial Development of Space
CMSS GOALS

- Produce and Evaluate Materials For Space Structures
- Develop Passive and Active Facilities For Materials Exposure and Analysis in Space
- To Develop Improved Materials Systems For Space Structures

CMSS PROPOSED FLIGHT PROGRAM

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Manifested Flights

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Limited Duration Space Environment Candidate Materials Exposure (LDCE) Experiment
LDCE-1,-2,-3

ATLANTIS (STS-46)
JULY, 1992

- 351 Experiment Samples (3/4" & 1")
- 3 LDCE Disks
- 40 Hours of Exposure
- 128 Nautical Miles Altitude

LDCE SPACEFLIGHT SAMPLE DISTRIBUTION

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<tr>
<td>U.S. Army-WPAFB</td>
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<td>TOTAL SAMPLES</td>
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<td>93</td>
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<tr>
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<td>Capacity (Total number of specimens: 351)</td>
<td>159</td>
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383
Long Duration Space Environment
Candidate Materials Exposure (LDSE)

LDSE OBJECTIVES

- To Provide a Long Term Materials Exposure Facility for Testing Large Numbers of Materials Samples in the Low Earth Orbit Environment
LDSE BENEFITS

• New Materials for Space
  - Lightweight, Oxygen Resistant Structural Materials
  - Corrosion Resistant Materials
  - Self-Healing Protective Coatings
  - High Vacuum Tribological Materials
  - Long-Life Optical Coatings

• New Materials for Earth
  - Lightweight Oxygen Tanks for Firefighters
  - High Strength, Corrosion Resistant Pipes and Vessels for Lower Cost Factories
  - Long-Life, Self-Healing Paints and Coatings
  - New Permanently Lubricated Motors and Machines
  - Solar Cells for Home Power Generation

LDSE OPERATIONAL SCENARIO

• 1st Launch in August, 1997 (LDSE-1)
  - Launch of CMSE Type Panel Modified to Mount on Space Station Freedom Truss Pointed into Ram Direction.

• Next Four Launches in FY 1998, 1999, 2000, and 2001 (LDSE -2, -3, -4, -5)
  - Mount to Space Station Truss
  - Annual EVA's Required for LDSE-1 may Service LDSE-2 and LDSE-3
  - Two Additional EVA's required for LDSE-4, -5

• Data Telemetered Through NASA-JSC to CWRU CMSS
The General Purpose Materials Flight Experiment Carrier Concept

MFLEX

MatLab-1 Experiment on the WakeShield Facility (WSF)

- Approximately 75 Instrumented Experiments
- Real Time Telemetry of Data
- Free Flyer Removes All Influence of Shuttle Environment
- 77 Hours of Exposure
- Flight on STS-60 Oct, 1993
- 190 Nautical Miles Altitude
MFLEX Base Configuration with MLA

- **Motorized Lid Assembly (MLA)**
  - Stainless Steel Lid Covers Active Samples
  - 61 sq.in. Active Sample Area
  - 55 sq.in. Passive Sample Area

- **Sensor Control Unit (SCU)**
  - Sensor Signal Conditioning
  - Motorized Lid Control

- **Experiment Control Unit (ECU)**
  - Data Acquisition Control
  - Carrier Communications
  - Able to Control up to 32 Separate SCU/MLA Units

MFLEX Distributed Structural Concepts

- **Motorized Lid Assembly (MLA)**

- **Sensor Control Unit (SCU)**

- **Experiment Control Unit (ECU)**

- **Sample Tray Assembly**
MOTORIZED LID ASSEMBLY

GUIDE CYLINDER

FLEXIBLE LID

DRIVE WHEEL

MOTOR
MFLEX Supports These Active Experiments

• 68 Actinometers
• 25 Strain Gauges
• 5 Acoustic Emission Sensors
• 72 Thermal Sensors
• 24 Ultraviolet, Visible Light and Solar Diodes

The MFLEX can provide up to 194 data channels per Sensor Control Unit and can accommodate up to 32 Sensor Control Units
MFLEX Flight Experiments:

- (11) MLA / SCA Test Assemblies
- (1) MLA / SCA / ECU Test Assembly
- (1) ECU controls all test assemblies
- 3 × 4 MFLEX packaging array

Figure 2 - CMSE Panel with Multiple MFLEX Experiments, Front View
Candidate Materials Space Exposure Experiment (CMSE)

- Approximately 1500 instrumented Experiments on Each Flight
- Flying on STS-68 (Oct '94), STS-75 (Jul '95), STS-03 (Aug '96), 1997
- 40-60 Hours of Exposure

MFLEX Flight Experiment Package Configured for Multiple Sample Trays
LDSE PAYLOAD READINESS

- Conceptual Design: FY 1994
- OCP Space Station Funding: FY 1995
- Detail Design: FY 1995
- Fabrication: FY 1996
- 1st Launch: 4th Quarter FY 1997

LDSE REQUIRED RESOURCES

Mass: 430 lbs each (5 required)
Volume: 79 in. tall x 48 in. wide x 12 in. deep
Power: 1.7 KW Peak .784 KW Average
Nitrogen: None
Liquid Heat Rejection: None
Avionics Heat Rejection: None
Water: None
Venting: None
Vacuum: None
Refrigerated Storage: None
Data Management: 30 K bytes/mbn. for each LDSE Panel
Video: Yes, 3x Camera Capability on Truss RMS
Uplink Command: Yes Open and Close Switches
Microgravity Level: N/A
Space Materials Evaluation Facility (SMEF)

- Standard Double Rack Aboard Space Station Freedom
- Evaluation
  - Space Processed Materials
  - Space Exposed Materials
  - Other Experiment Support
- Equipment
  - Scanning Electron Microscope
  - Variable Angle Scanning Ellipsometer
  - Fourier Transform Infrared Spectrometer

For Further Information on LDSE or Other CMSS Experiments

contact:

John F. Wallace
(216) 368-4222
Fax (216) 368-6329
POTENTIAL PRESSURIZED PAYLOADS;
FLUID AND THERMAL EXPERIMENTS

Presented by Theodore D. Swanson
Advanced Development and Flight Experiment Section
NASA Goddard Space Flight Center

ABSTRACT

Space Station Freedom (SSF) presents the opportunity to perform long term fluid and thermal experiments in a microgravity environment. This presentation provides perspective on the need for fluids/thermal experimentation in a microgravity environment, addresses previous efforts, identifies possible experiments, and discusses the capabilities of a proposed fluid physics/dynamics test facility.

Numerous spacecraft systems use fluids for their operation. Thermal control, propulsion, waste management, and various operational processes are examples of such systems. However, effective ground testing is very difficult. This is because the effect of gravity induced phenomena, such as hydrostatic pressure, buoyant convection, and stratification, overcome such forces as surface tension, diffusion, electric potential, etc., which normally dominate in a microgravity environment. Hence, space experimentation is necessary to develop and validate a new fluid based technology.

Two broad types of experiments may be performed on SSF; basic research and applied research. Basic research might include experiments focusing on capillary phenomena (with or without thermal and/or solutal gradients), thermal/solutal convection, phase transitions, and multiphase flow. Representative examples of applied research might include two-phase pressure drop, two-phase flow instabilities, heat transfer coefficients, fluid tank fill/drain, tank slosh dynamics, condensate removal enhancement, and void formation within thermal energy storage materials.

In order to better support such fluid/thermal experiments on board SSF, OSSA has developed a conceptual design for a proposed Fluid Physics/Dynamics Facility (FP/DF). The proposed facility consists of one facility rack permanently located on SSF and one experimenter rack which is changed out as needed to support specific experiments. This approach will minimize the on-board integration/deintegration required for specific experiments. The FP/DF will have acceleration/vibration compensation, power and thermal interfaces, computer command/data collection, a video imaging system, and a portable glovebox for operations. This facility will allow real-time astronaut interaction with the testing.
1992 SPACE STATION UTILIZATION CONFERENCE
-AUGUST 3-6, 1992; HUNTSVILLE, ALABAMA-

POTENTIAL PRESSURIZED PAYLOADS;
FLUID AND THERMAL EXPERIMENTS

THEODORE D. SWANSON
NASA/GODDARD

OUTLINE

• PROVIDE PERSPECTIVE ON NEED FOR
  FLUID/THERMAL PHYSICS EXPERIMENTATION
  IN A MICROGRAVITY ENVIRONMENT

• ADDRESS PREVIOUS EFFORTS

• IDENTIFY LIKELY TYPES OF EXPERIMENTS

• DISCUSS PROPOSED SPACE STATION FREEDOM
  TEST CAPABILITIES FOR FLUID PHYSICS/DYNAMICS
FLUID AND THERMAL EXPERIMENTS

BACKGROUND

- NUMEROUS SPACECRAFT SYSTEMS UTILIZE FLUIDS FOR OPERATION
  - THERMAL CONTROL, PROPULSION, WASTE MANAGEMENT, OPERATIONAL PROCESSES, ETC.

- GROUND TESTING SEVERELY COMPROMISED BY PRESENCE OF GRAVITY
  - HYDROSTATIC PRESSURE, BUOYANT CONVECTION, SEDIMENTATION, AND STRATIFICATION OVERCOME EFFECTS OF SURFACE TENSION, DIFFUSION PHENOMENA, ELECTRIC POTENTIAL, ETC.

BOTH BASIC SCIENCE AND SPACECRAFT TECHNOLOGY WILL BENEFIT FROM THE STUDY OF FLUID/THERMAL PHENOMENA IN A MICROGRAVITY ENVIRONMENT

EFFECT OF GRAVITY ON FLOW REGIME

TWO-PHASE FLOW REGIMES DEMONSTRATING EFFECT OF DIFFERENT GRAVITY LEVELS
(LEARJET FACILITY; AIR/WATER IN 1.27-cm-1.d. TUBE; SUPERFICIAL GAS VELOCITY, ~0.14 m/sec; SUPERFICIAL LIQUID VELOCITY, ~0.07 m/sec).
FLUID AND THERMAL EXPERIMENTS
-BACKGROUND, CONTINUED-

• PREVIOUS FLUID/THERMAL RESEARCH PROGRAMS
  OF THE 1960’s, 1970’s, AND EARLY 1980’s
  IDENTIFIED MANY CRITICAL ISSUES, BUT THE
  PRIMARY EMPHASIS WAS ON SPECIFIC COMPONENTS
  AND SYSTEMS - NO GENERIC TECHNOLOGY BASE
  WAS DEVELOPED

• PREVIOUS WORKING GROUPS ALL IDENTIFIED
  SIMILAR NEEDS;
  - IN-SPACE RESEARCH, TECHNOLOGY, AND
    ENGINEERING WORKSHOP; OCTOBER 1985,
    WILLIAMSBURG
  - MICROGRAVITY FLUID MANAGEMENT SYMPOSIUM,
    SEPTEMBER, 1986, LeRC
  - WORKSHOP ON TWO-PHASE FLUID BEHAVIOR IN
    A SPACE ENVIRONMENT; JUNE, 1988, OCEAN CITY
  - IN-STEP 88; DECEMBER, 1988, ATLANTA

PREVIOUS FLUID/THERMAL PHYSICS
MICROGRAVITY EXPERIMENTATION

PREVIOUS MICROGRAVITY TESTING HAS GENERALLY
BEEN OF VERY LIMITED TIME DURATION

• DROP TOWERS - A FEW SECONDS
• AIRCRAFT - 20 TO 25 SECONDS
• SOUNDING ROCKETS, BALLOONS - MINUTES
• SHUTTLE - A FEW DAYS
  - NASA/GODDARD TEMP 2A3 EXPERIMENT ON STS 46

MANY RESEARCHERS FEEL THAT WHILE A TEST DURATION
OF SECONDS MAY BE ACCEPTABLE FOR SUCH PHENOMENA AS
FLOW REGIMES, MUCH LONGER TIME DURATIONS ARE NEEDED
TO STUDY OTHER PHENOMENA
COMPARISON OF MICROGRAVITY ENVIRONMENTS

SPACE STATION FREEDOM OFFERS UNIQUE ENVIRONMENT FOR THERMAL/FLUID EXPERIMENTS

CHARACTERISTIC TIMES AND ACCELERATION LEVELS OF MICROGRAVITY LABORATORY FACILITIES.

TYPES OF EXPERIMENTS

TWO BROAD CATEGORIES OF EXPERIMENTS;

• BASIC RESEARCH
  - NO SPECIFIC APPLICATION; INVESTIGATION OF BASIC FLUID AND THERMAL PHENOMENA

• APPLIED SCIENCE
  - GOAL IS TO UNDERSTAND PHENOMENA SO AS TO SOLVE A GIVEN DESIGN PROBLEM
BASIC SCIENCE EXPERIMENTS

FIVE BROAD CLASSES:

• CAPILLARY PHENOMENA IN A ISOTHERMAL/ISO-SOLUTAL ENVIRONMENT
• CAPILLARY PHENOMENA WITH THERMAL/SOLUTAL GRADIENTS
• THERMAL/SOLUTAL CONVECTION
• FIRST AND SECOND ORDER PHASE TRANSITIONS IN A STATIC FLUID
• MULTIPHASE FLOW

REFERENCE; LOW GRAVITY FLUID PHYSICS: A PROGRAM OVERVIEW
LEWIS RESEARCH CENTER, CLEVELAND, OHIO

APPLIED SCIENCE EXPERIMENTS

REPRESENTATIVE EXAMPLES

• TWO-PHASE PRESSURE DROP
• TWO-PHASE FLOW INSTABILITIES
• TWO-PHASE FLOW THROUGH LINES, DUCTS, AND FITTINGS
• HEAT TRANSFER COEFFICIENTS
• FLUID TANK FILL/DRAIN
• FLUID TANK SLOSH DYNAMICS
• FLUID REORIENTATION WITHIN A TANK
• CONDENSATE REMOVAL ENHANCEMENT
• VOID FORMATION/DISTRIBUTION IN THERMAL ENERGY STORAGE MATERIALS
PROPOSED SPACE STATION FREEDOM
FLUID PHYSICS RESEARCH CAPABILITIES

- NASA'S OSSA TASKED LeRC TO CONDUCT A WORKSHOP TO DEFINE A FLUID PHYSICS/DYNAMICS FACILITY (FP/FD) FOR SSF

- RESULTING CONCEPTUAL DESIGN IS A MODULAR, TWO RACK FACILITY;
  - FACILITY RACK; PERMANENT, BUT UPGRADABLE
  - EXPERIMENT RACK; EXPERIMENT SPECIFIC MODULES AND EQUIPMENT

- TWO-RACK CONCEPT CHOSEN BECAUSE;
  - MAXIMIZES VOLUME THAT CAN BE REORIENTED WITH RESPECT TO THE QUASI-STEADY STATE ACCELERATION VECTOR
  - MINIMIZES ON-BOARD INTEGRATION/DEINTEGRATION EFFORT FOR EXPERIMENT SPECIFIC HARDWARE

- REFERENCE: NASA TECHNICAL MEMORANDUM, "STATUS REPORT ON CONCEPTUAL DESIGN FOR THE SPACE STATION FREEDOM FLUID PHYSICS/DYNAMICS FACILITY"

MODULAR CONCEPT FOR PROPOSED SSF
FLUID PHYSICS/DYNAMICS FACILITY

- REFERENCE: NASA TECHNICAL MEMORANDUM, "STATUS REPORT ON THE CONCEPTUAL DESIGN FOR THE SPACE STATION FREEDOM FLUID PHYSICS/DYNAMICS FACILITY"
LAYOUT OF PROPOSED SSF
FLUID PHYSICS/DYNAMICS FACILITY

- SURFACE TENSION INDUCED INSTABILITIES
- SURFACE TENSION DRIVEN CONVECTION
- FREE SURFACE PHENOMENA
- BUBBLE/DROPLET DYNAMICS
- THERMAL AND DOUBLE DIFFUSE CONVECTION
- MULTIPHASE FLOW
- FIRST ORDER TRANSITIONS
- CHEMICAL DEPOSITION
- THERMAL GRADIENT EFFECTS ON ENTRY-FLOW
- FLUID PHENOMENA DURING SOLIDIFICATION
- FLUID MIXTURE HEAT AND MASS TRANSFER
SSF MICROGRAVITY ENVIRONMENT

- NO FIRM MICROGRAVITY REQUIREMENT YET ESTABLISHED
- ANTICIPATED ENVIRONMENT HAS THREE ELEMENTS;
  - QUASI-STEADY ACCELERATION (10^-5 G's)
    - 10^-5 G's, 37° DEGREES
  - THREE MAJOR FACTORS;
    - GRAVITY GRADIENT
    - ROTATIONAL
    - ATMOSPHERIC DRAG
- OSCILLATORY ACCELERATIONS
  - ROTATING MACHINERY, CREW ACTIVITIES, STRUCTURAL
- TRANSIENT ACCELERATIONS
  - CREW, THRUSTER FIRINGS, VENTING, DOCKING, EQUIPMENT ON/OFF

PROPOSED FP/DF CAPABILITIES

- Rotating quasi-steady acceleration alignment system (68 cm dia.)
- Passive vibration isolation techniques
- Power; 6 KW of 120 VDC to facility rack,
  3 KW of 120 VDC to equipment rack,
  28 VDC and 400 Hz AC as required
- Thermal; interface heat exchanger, cold plate,
  air-to-air cooling
- FP/DF computer - node on SSF computer; three data links, up to 100 MB/SEC,
  variety of sensor accommodations
- Video imaging system
- Portable glovebox
PROPOSED SSF FP/DF QUASI-STEADY ACCELERATION ALIGNMENT SYSTEM

PROPOSED SSF FP/DF PORTABLE GLOVEBOX CONCEPT
BENEFITS OF SSF
FLUID PHYSICS/DYNAMICS FACILITY

• LONG DURATION (MONTHS-YEARS)
• MICROGRAVITY AT LEVEL REPRESENTATIVE OF LARGE SPACE STRUCTURES
• CREW AVAILABILITY FOR OPERATIONS
• REAL TIME HUMAN OBSERVATION
• CREW AVAILABLE FOR MODIFICATION/REPAIR
• INCREASED TEST MATRIX FLEXIBILITY

ISSUES FOR FLUIDS/THERMAL TESTING ON SSF

• ACCELERATIONS OF 10^-5 TO 10^-6 G's MAY BE LARGE ENOUGH TO AFFECT SOME PROCESSES
  - IMPACT UNKNOWN
• SAFETY CONCERNS LIMIT USE OF OPERATING FLUIDS TO BENIGN FLUIDS SUCH AS WATER, ALCOHOL, R-113, AND SILICON OILS
• MODERATE PHYSICAL SIZE
O-G LIFE SUPPORT FOR SPACE STATION FREEDOM

Presented by Matthew Kolodney
Lockheed Engineering and Sciences Company
NASA Johnson Space Center

ABSTRACT

Optimal design of spacecraft environmental control and life support systems (ECLSS) for long-duration missions requires an understanding of microgravity and its long-term influence on ECLSS performance characteristics. This understanding will require examination of the fundamental processes associated with air revitalization and water recovery in a microgravity environment. Short-term testing can be performed on NASA’s reduced gravity aircraft (a KC135), but longer tests will need to be conducted on the shuttle or Space Station Freedom.

Conceptual designs have been prepared for ECLSS test beds that will allow extended testing of equipment under microgravity conditions. Separate designs have been formulated for air revitalization and water recovery test beds. In order to allow testing of a variety of hardware with minimal alteration of the beds themselves, the designs include storage tanks, plumbing, and limited instrumentation that would be expected to be common to all air (or water) treatment equipment of interest. In the interest of minimizing spacecraft/test bed interface requirements, the beds are designed to recycle process fluids to the greatest extent possible. In most cases, only cooling water and power interfaces are required.

A volume equal to that of two SSF lockers was allowed for each design. These bed dimensions would limit testing to equipment with a 0.5- to 1.5-person-equivalent throughput. The mass, volume, and power requirements for the air revitalization test bed are estimated at 125-280 kg, 1.0-1.4 m³, and 170-1070 W. Corresponding ranges for the water recovery test bed are 325-375 kg, 1.0-1.1 m³, and 350-850 W. These figures include individual test articles and accompanying hardware as well as the tanks, plumbing, and instrumentation included in the bed designs. Process fluid weight (i.e. water weight) is also included.
ZERO - G LIFE SUPPORT RESEARCH

M. Kolodney, Lockheed Engineering and Sciences Co.

L. Dall-Bauman, NASA-JSC

Presented at
Space Station Freedom Utilization Conference
Huntsville AL
August 3-6, 1992

RATIONALE

• Optimal design of spacecraft ECLSS for long-duration missions requires an understanding of microgravity and its long-term influence on ECLSS performance.

• Such understanding requires examination of fundamental processes associated with air revitalization and water recovery in a microgravity environment.

• Short-term testing can be performed on NASA's reduced-gravity aircraft (KC135), but longer tests will need to be conducted on the shuttle or SSF.
CONSTRAINTS

• Bed must fit in two adjacent station lockers, each with dimensions 0.91 m x 0.99 m x 1.83 m.

• Limited space available means that full-scale (i.e. 4-person) hardware cannot be tested.

• SSF-test bed interfaces limited to
  • electric power
  • cooling water at 4°C
  • air

COMMONALITY

• Separate beds have been designed for testing ARS and WRMS equipment.

• Vastly different flow rates and compressibilities require dissimilar equipment, line sizing, and instrumentation.

• A common test bed would require parallel flow paths and equipment to allow circulation of gases and liquids.

• Many air revitalization processes are continuous, while most water recovery subsystems include batch processes.
TEST BED CLOSURE

- Due to limited SSF-test bed interfacing, test bed should be closed to the greatest extent possible.

- In some cases, full closure may be unrealistic.
  
  - Example: Bosch reactor
    
    - To close bed with respect to carbon, solid carbon would have to be recovered and oxidized to CO2.
    
    - To close bed with respect to hydrogen, product water would have to be electrolyzed.
    
    - Equipment necessary to close test bed would drive mass, volume, and power requirements beyond limits of bed.

BED DESIGN PHILOSOPHY

- Test beds have been designed in a modular fashion in order to allow testing of a variety of equipment.

- To allow testing of different hardware with minimal bed modification, bed designs include storage tanks, plumbing, and limited instrumentation expected to be common to all equipment of interest.

- Each bed allows space for insertion of "experiment packages", which will include test articles as well as instrumentation, plumbing, and controls specific to test articles.
ARS TEST BED HARDWARE

- surge/storage tank
- CO₂ and O₂ sensors
- condensing heat exchanger
- humidifier
- adsorbent bed
- fan
- electric heater
- control package

SCHEMATIC OF POSSIBLE EXPERIMENT PACKAGE

adapted from final report on SAWD II, SVHSER 10634
## ARS TEST BED MASS, VOLUME, AND POWER SUMMARY

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<th>Mass (kg)</th>
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<th>Power (W)</th>
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<td>93</td>
<td>0.8</td>
<td>129</td>
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<td>experiment package</td>
<td>32 - 187</td>
<td>0.2 - 0.6</td>
<td>41 - 941</td>
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<td><strong>TOTAL</strong></td>
<td><strong>125 - 280</strong></td>
<td><strong>1.0 - 1.4</strong></td>
<td><strong>170 - 1070</strong></td>
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## WRMS TEST BED HARDWARE

- feed/product tank
- pretreatment storage
- posttreatment
- two heat exchangers
- control package

- feed pump
- pretreatment pump
- filter
- temperature control bath
SUMMARY

- Long-term testing of life support hardware under microgravity conditions is essential for design of optimal life support systems.

- Separate test beds have been designed to enable testing of ARS and WRMS hardware on SSF.

- ARS test bed requirements are estimated at 125 - 280 kg, 1.0 - 1.4 m³, and 170 - 1070 W.

- WRMS test bed requirements are estimated at 325 - 375 kg, 1.0 - 1.1 m³, and 350 - 850 W.

- The above estimates include test articles and accompanying hardware in addition to tanks, plumbing, and instrumentation contained in bed infrastructure.
WP-2 ATTACHED PAYLOAD ACCOMMODATIONS

Presented by Jim Scheib
Space Station Division
McDonnell Douglas

ABSTRACT

The presentation provides an overview of the current SSFP attached payload accommodations on the U.S. truss. The overview includes discussions on the four attach sites, the power architecture, thermal control, DMS provisions and the mechanical attach mechanism. The presentation concludes with a description of a McDonnell Douglas concept for an attached payload pallet designed to take advantage of the four sites and existing SSF hardware. This presentation should provide the payload community with a basic understanding of the SSF attached payload utility ports and aid in attached payload concept development.
WP-2 ATTACHED PAYLOAD
ACCOMMODATIONS

June 1992

Jim Scheib, Manager
User Engineering Integration
MDSSC Space Station Division
(714) 896-3311 x60457

Space Station Freedom

McDonnell Douglas
GE
Honeywell
IBM
Lockheed

6/8/92

Accommodations:
- Power: 3 kW each site, 6 kW aggregate
- Data: 1533 local bus-256 kbps down (FDOS screening potential)
- Use of common station attachment mechanism (modified propulsion module assembly structure)

*Pallets and payloads are representative only.
NOVEMBER 12 SSCB AND ATTACHED PAYLOAD CR

The November 12 SSCB and the parameters set forth in the Attached Payload CR #BB003113B require accommodations for attached payload as follows:

- **Number of sites:** at least 4 separate sites for attached payloads
  - **Viewing:** view nadir, zenith, ram and wake direction without significant occultation by SSMB
  - **Clearance Envelopes:** attach faces of about 5x6 ft on S2 and 6x13 ft on the S1 and P1 sites, and 7 ft height at each site

- **Utility Ports:** each site contains at least 1 port
  - **Power:** 3 kW peak per port (redundant power feed)
    - 6 kW total peak aggregate supplied to all ports
  - **Thermal:** payload provided
  - **Data:** 1553 Payload Local Bus with external FDDI network fibers and cables for later hook up
  - **Mechanical Attachment:** each attached payload site will contain 1 suitable mechanical attachment

---

ATTACHED PAYLOAD UTILITY PORTS

- **Starboard (MTC) Locations:**
  - S2-F4-B1: pre-integrated attachment on Face 4 (5' x 6' attach face) with viewing in the Nadir and Wake directions (potential for Ram and Zenith viewing also)
  - S1-F4-B6: attachment over the grapple fixtures with no structural impact (6' x 13' attach face), viewing in Nadir, Zenith, Ram and Wake directions

- **Port (post MTC) Locations:**
  - P1-F2- B2: attachment over the utility trays (6' x 13' attach face), unobstructed view in Zenith, Ram and Wake directions
  - P1-F6- B2: attachment over the utility trays (6' x 13' attach face), unobstructed view in Nadir, Ram and Wake directions, common with P1-F2 location

Note: all sites provide a minimum height of 7 ft - see operational envelopes pages 10 through 12
ON-ORBIT CONFIGURATION SHOWING PRIME PAYLOAD ATTACHMENT SITES

P1-F2-B1&2
S2-F4-B1
S1-F4-B6
P1-F6-B1&2

Space Station Freedom
McDonnell Douglas • GE • Honeywell • IBM • Lockheed

S2 (MB-2) SEGMENT ATTACHED PAYLOAD OPERATIONAL ENVELOPE

S-Band Antennas
Star Trackers
S2/S3 Bulkhead
Propulsion Module

Space Station Freedom
McDonnell Douglas • GE • Honeywell • IBM • Lockheed
POWER ACCOMMODATIONS APPROACH

- The existing Electrical Power System (EPS) design was used
  - No new DC to DC Convertor Units (DDCUs) are required, which would also require adding new Main Bus Switching Units (MBSUs)
  - Existing Secondary Power Distribution Assemblies (SPDAs) already in place along the truss are used
  - No impact on the growth of the overall EPS system to PMC

- Power accommodations provide payloads with continuous power (power levels depend on Station loads but do not exceed 6 kW total)
  - Each port is connected to a utility SPDA on each side of the truss making the ports single failure tolerant (in case of SPDA failure up to 500 Watts may be available)
  - If a utility SPDA fails on one side of the Station and the Mobile Transporter is using the utility SPDA on the other side, no keep-alive power to payloads can be guaranteed

---

PROPOSED ATTACHED PAYLOAD POWER ARCHITECTURE

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Space Station Freedom

6/4/92

McDonnell Douglas • GE • Honeywell • IBM • Lockheed
ATTACHED PAYLOAD THERMAL CONTROL

- Payloads are required to provide their own thermal control
- Payloads must be assessed on an individual basis to determine thermal effects at the appropriate attached site and orientation. The following considerations must be addressed:
  - Operational/non-operational temperature ranges experienced by the payload components or its individual ORUs
  - What types of thermal coatings/insulation can be used to enhance the desired temperature range
  - What size radiators are needed to dissipate heat and what size heaters are needed to make-up heat
- Design-to thermal optical properties, radiator sizes, and insulation requirements at each payload site must be determined by integrating the payload model into a full Space Station model to properly size Passive Thermal Control Systems (PTCS) for each payload
- Preliminary thermal analyses for two example payloads: the Cosmic Dust Collection Facility and the Orbital Debris Collision Warning System were performed under this study

---

DMS ACCOMMODATIONS

- SSCB has baselined 1553 local bus service
- FDDI scarring is possible but has not been finalized yet
- Interface Description:
  - DMS accommodations are provided by extending two 1553 local busses from SDP 7 in the Lab Element Control Workstation rack in the U.S. Lab
    - One 1553B bus to the port APP sites and a second separate 1553B bus to the starboard APP sites
  - The two Local Busses share the same Bus Interface Unit (BIU) with separate Bus Interface Adapters (BIA) to service each of the Payload Local Busses

  Note: requires the addition of one BIU in SDP-7
ATTACHMENT ACCOMMODATIONS SUMMARY

- Accommodations include provisions for Propulsion Module Attach Structure (PMAS) at each payload port
  - PMAS is composed of mechanical latch, umbilical mechanism, guide vanes, wire harness and support structure
  - PMAS and support structure are not pre-integrated and are installed with EVA at the time of payload first use
  - Installation of attached payload pallet to PMAS will utilize the RMS for positioning and EVA for final alignment
  - PMAS standard attachment interface provides payload community with the flexibility to connect single or multiple payloads at each location (e.g. large payloads, gas cans or SARR pallet)
  - On segment P1 faces 2 and 6 the PMAS and the payload(s)/payload pallet will swing away from the utility trays if on-orbit utility tray servicing is ever necessary
Space Station Freedom

Propulsion Module Attach Structure (PMAS)

- Starboard PIT Segment
- Propulsion Module Attach Structure (PMAS)
- APA - McDonnell Douglas Attached Payload Assembly

Small and Rapid Response Payloads

- Payload Avionics
- Mini Pallet for External Payloads (MPEP)
- Wing ASAP

WP-2 Standard Boxes for Scientific Payloads (2 Options)

- Pallet for External Payloads (PEP)
- Center Adaptable Subplate for Attached Payloads (Center ASAP)

APA Options

- Robotic Interface

Wing ASAP

McDonnell Douglas Attached Payload Assembly (APA)
Microgravity Science in the U.S.A. involves research in fluids science, combustion science, materials science, biotechnology and fundamental physics. The purpose is to achieve a thorough understanding of the effects of gravitational body forces on physical phenomena relevant to those disciplines. This includes the study of phenomena which are usually overwhelmed by the presence of gravitational body forces and, therefore, chiefly manifested when gravitational forces are weak. In the pragmatic sense, the research involves gravity level as an experimental parameter.

Calendar year 1992 is a landmark year for research opportunities in low earth orbit for Microgravity Science. For the first time ever, three Spacelab flights will fly in a single year. IML-1 was launched on January 22; USML-1 was launched on June 25; and, in September, SL-J will be launched. A separate flight involving two cargo bay carriers, USMP-1, will be launched in October. From the beginning of 1993 up to and including the Space Station era (1997), nine flights involving either Spacelab or USMP carriers will be flown. This will be augmented by a number of middeck payloads and get away specials flying on various flights.

All of this activity sets the stage for experimentation on Space Station Freedom. Beginning in 1997, experiments in Microgravity Science will be conducted on Station. Facilities for doing experiments in protein crystal growth, solidification and biotechnology will all be available. These will be joined by middeck-class payloads and the microgravity glove box for conducting additional experiments. In 1998, a new generation protein crystal growth facility and a facility for conducting combustion research will arrive. A fluids science facility and additional capability for conducting research in solidification, as well as an ability to handle small payloads on a quick response basis, will be added in 1999. The year 2000 will see upgrades in the protein crystal growth and fluids science facilities. From the beginning of 1997 to the fall of 1999 (the “man-tended capability” era), there will be two or three utilization flights per year. Plans call for operations in Microgravity Science during utilization flights and between utilization flights. Experiments conducted during utilization flights will characteristically require crew interaction, short duration and less sensitivity to perturbations in the acceleration environment. Operations between utilization flights will involve experiments that can be controlled remotely and/or can be automated. Typically, the experiments will require long times and a pristine environment. Beyond the fall of 1999 (the “permanently-manned capability” era), some payloads will require crew interaction; others will be automated and will make use of telescience.
Microgravity Science and Applications Division
Research Objectives, Opportunities, and Facilities

Presented to:
Space Station Freedom Utilization Conference
August 3 - 6, 1992
Huntsville, Alabama

Robert J. Bayuzick
Develop a comprehensive research program in fluids science, combustion science, materials science, biotechnology, and fundamental physics for the purpose of attaining a structured understanding of gravity-dependent physical phenomena and those physical phenomena made obscure by the effects of gravity.

- Multiphase flow and heat transfer
- Suspension/colloid/granular media mechanics
- Solid-fluid interface dynamics
- Capillary phenomena
- Magneto/electrohydrodynamics
- Transport phenomena
Combustion Science Research Areas

- Ignition, smolder, solid materials
- Gaseous diffusion flames
- Gaseous premixed flames
- Heterogeneous (particles and droplets)
- Metals and combustion synthesis

Materials Science Research Areas

Electronic and Photonic Materials
Metals and Alloys
Glasses and Ceramics

or

Crystal Growth
Solidification Fundamentals
Thermophysical Properties
Biotechnology Research Areas

- Cell physiology
- Cell differentiation
- Protein crystal growth
- Biological separations

Fundamental Physics Research Areas

- Critical point phenomena
- Gravitational physics
FLIGHT OPPORTUNITIES -- THE PRESENT

- Four MSAD missions in CY92:
  
  **IML-1**  - successful mission: January 22 - 30, 1992
  
  **USML-1**  - successful mission: June 25 - July 9, 1992
  
  **Spacelab-J**
  
  **USMP-1**
### International Microgravity Laboratory (IML-1)
#### Microgravity Science and Applications

<table>
<thead>
<tr>
<th>Apparatus/Experiment</th>
<th>Acronym</th>
<th>Principal Investigator</th>
<th>Country of Origin</th>
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<tr>
<td><strong>Fluids Experiment System</strong></td>
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<tr>
<td>- A Study of Solution Crystal Growth in Low Gravity</td>
<td>FES</td>
<td>Dr. R. B. Lal</td>
<td>U.S.A.</td>
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<td>- Casting and Solidification Technology</td>
<td>TGS</td>
<td>Dr. M. H. McCay</td>
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<td><strong>Vapor Crystal Growth System</strong></td>
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<td><strong>Mercuric Iodide Crystal Growth</strong></td>
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<td><strong>Protein Crystal Growth</strong></td>
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<td><strong>Organic Crystal Growth Facility</strong></td>
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<td><strong>Cryostat</strong></td>
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<tr>
<td>- Protein Crystal Growth in Cryostat</td>
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<td>Dr. McPherson</td>
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<tr>
<td>- B-galactosidase/Inhibitor-Single Crystal Growth</td>
<td>TGS</td>
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<td>Germany</td>
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<tr>
<td>- Crystal Growth of Electrogenic Membrane Protein Bacteriorhodopsin</td>
<td>CAST</td>
<td>Dr. G. Wagner</td>
<td>Germany</td>
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<td><strong>Critical Point Facility</strong></td>
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<td>- Critical Fluid Thermal Equilibrium</td>
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<td>ESTEC</td>
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<td>- Heat and Mass Transport at the Critical Point</td>
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<td>- Light Scattering and Interferometry Experiments</td>
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<tr>
<td><strong>Space Acceleration Measurement System</strong></td>
<td>SAMS</td>
<td>Dr. R. DeLombard</td>
<td>U.S.A.</td>
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### U.S. Microgravity Laboratory (USML-1)
#### Microgravity Science and Applications

<table>
<thead>
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<tr>
<td><strong>Crystal Growth Furnace (CGF)</strong></td>
<td>MSFC</td>
<td>D. Larson</td>
<td>A. Lehoczky</td>
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<td>- Orbital Processing of High Quality Cd-Te</td>
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<td>- Crystal Growth of II-VI Semiconducting Alloys by Solidification</td>
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<td>- Study of Dopant Segregation Behavior During Growth of Ga-As in Microgravity</td>
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<td>- Vapor Growth of Hg-Cd-Te in Microgravity</td>
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<td>JPL</td>
<td>D. Matthiesen</td>
<td>H. Wiedemeyer</td>
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<td>- Science and Technology of Surface Controlled Phenomena</td>
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<td>- Drop Dynamics Investigation</td>
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<td>- Measurement of Liquid-Liquid Interface Tension of a Compound Drop</td>
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<td><strong>Astroculture (ASC)</strong></td>
<td>Wisconsin Ctr. for Auto. &amp; Robotics</td>
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### Spacelab J (SL-J)
**Microgravity Science Experiments**

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<td>Bubble Behavior Experiment Unit</td>
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<td>Crystal Growth Experiment Furnace</td>
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<td>Free Flow Electrophoresis Unit</td>
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<td>Gas Evaporation Experiment Facility</td>
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<td>Gradient Heating Furnace</td>
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<td>Marangoni Convection Experiment Unit</td>
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<td>Organic Crystal Growth Experiment Facility</td>
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### U.S. Microgravity Payload (USMP-1)
**Microgravity Science and Applications Experiments**

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### Microgravity Science and Applications Division Baseline Plan: 1994 - 2004

#### SPACE MISSIONS

**Condensed Matter Physics**
- Lambda Point Experiment
- Critical Fluid Light Scattering Experiment
- Critical Fluid Viscosity Measurement Experiment
- Low Temperature Research Facility
- Satellite Test of Equivalence Principle

**Fluids & Transport Phenomena**
- Surface Tension Driven Convection Experiment
- Drop Physics Module
- Critical Point Facility (P)
- Bubble, Drop, and Particle Unit (F)
- Geophysical Fluid Flow Cell
- Mechanics of Granular Materials
- Advanced Fluidics Module
- Advanced Fluidics Module
- Fluid Physics/Dynamics Facility
- Modulator Controllability Processing Facility

**Combustion Science**
- Solid Surface Combustion Experiment
- Advanced Combustion Modules
- Advanced Combustion Module
- Modulator Combustion Facility

#### FUNDAMENTAL SCIENCE

**Isothermal Dendritic Growth Experiment**
- TEMPLES (F)
- Large Isothermal Furnace (F)
- Space Station Furnaces Facility

**Metals and Alloys**
- Drop Physics Module
- Modular Controllability Processing Facility

**Glasses and Ceramics**
- Electronic & Photoconductive Materials
- Crystal Growth Furnace
- MEPHISTO (F)
- Advanced Automated Directional Solidification Furnace
- Programmable Multizoned Furnace
- Space Station Furnaces Facility

**Electromagnetic**
- Solid Surface Combustion Experiment
- Advanced Combustion Modules
- Advanced Combustion Module
- Modulator Combustion Facility

#### MATERIALS SCIENCE

**BIOTECHNOLOGY**

**SO & DA**
- Space Acceleration Measurement System
- Geobees Experiment Module

**R & A**
- Drop Tubes/Towers
- Parabolic Flights
- Sounding Rockets

**ATD**
- Advanced Furnace Technology
- Non-Contact Temperature Measurement
- Laser Light Scattering Experiment

### Microgravity Science and Applications Division Planning Manifest

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<thead>
<tr>
<th>CY91</th>
<th>CY92</th>
<th>CY93</th>
<th>CY94</th>
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<td>FES-WAGS</td>
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### NOTES:
- (LRO) Launch Readiness Dates and STS flight numbers from SSP Baseline Manifest, Mar. 20, 1992
- (LD) Launch Date
- (I) Indicates non-U.S. hardware on which U.S. investigators are flying (International)
- (U) Indicates non-MSAD hardware in which MSAD investigators are flying
- * Indicates enhanced/upgraded hardware
- ** Will not fly if Space Station is available

207-001 (NCAW 07/06/92)
## Microgravity Science and Applications Division
### Planning Manifest

#### CY96
- **USML-3 (STS-96)**
  - LD - 1/19/97
  - STDCE, APEX, SAMS, DCE
  - SL-2 (STS-96)

#### CY97
- **USMP-5 (STS-97)**
  - LD - 4/12/97
  - IDGE, SAMS, SAMS, MEPHISTO (I)

#### CY98
- **USMP-6 (STS-98)**
  - LD - 3/18/98
  - IDGE, SAMS, SAMS, MEPHISTO (I), LTRF-20

#### CY99
- **USMP-7 (STS-99)**
  - LD - 6/22/99
  - SAMS, SAMS

#### CY00
- **USMP-4 (STS-00)**
  - LD - 1/25/99
  - AADSF (A-1), SAMS, SAMS, MEPHISTO (I)

### Microgravity Science and Applications Division
### Planning Manifest

#### CY91
- **MIDDECK**
  - OR GAS
  - **(STS-37)**
    - LD - 4/5/91
    - PCG-III:4
    - **(STS-49)**
      - LD - 3/24/92
      - GaAs (GAS)
      - **(STS-54)**
        - SSCE:3
        - PCG:III:5
        - SAMS:1
        - **(STS-57)**
          - MLP:12/3/92
          - SAMS:1

#### CY92
- **MIDDECK**
  - OR GAS
  - **(STS-37)**
    - Cell Cult. DSO (1)

#### CY93
- **MIDDECK**
  - OR GAS
  - **(STS-49)**
    - APEX (4yr)
    - PCG (4yr)
    - **(STS-54)**
      - Coop Prog. (1yr)
      - SAMS (3yr)
      - **(STS-57)**
        - Coop Prog. (1yr)

#### CY94
- **MIDDECK**
  - OR GAS
  - **(STS-37)**
    - SAMS (3yr)
    - **(STS-49)**
      - APEX (3yr)
      - **(STS-54)**
        - SAMS (2yr)
        - **(STS-57)**
          - Coop Prog. (2yr)

#### CY95
- **MIDDECK**
  - OR GAS
  - **(STS-37)**
    - SAMS (3yr)
    - **(STS-49)**
      - APEX (3yr)
      - **(STS-54)**
        - SAMS (2yr)

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**FREEFLYER**
- **(STS-71)**
  - LD - 2/22/95
  - EURECA-2L (I)
  - Coop. Prog.
### Microgravity Science and Applications Division

**Planning Manifest**

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### Planned Research Announcements

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Microgravity Science and Applications
Division FY92 Budget by Program

- Science: $1,995K
- Biotechnology: $2,183K
- Protein Crystal Growth (PCG): $4,761K
- Containerless: $14,908K
- Advanced Technology Development (ATD): $1,870K
- HQ & Center Support: $26,596K
- Research and Analysis (R & A): $16,600K
- Fundamental Science: $9,147K
- Flows: $9,658K
- Combustion: $6,810K
- Solidification: $21,025K

Total: $120,800K

Microgravity Science and Applications Space Station Facilities
Integrated Launch Schedule

Overall Flight Sequence

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Utilization Flight Increment

- 13 Days Shuttle Docked at Space Station Freedom
- Crew-Tended Payload Operations
- Safe & Secure
- Remote Payload Operations
- Return

MSAD Space Station Payload Traffic Model (April 1992)

- Protein Crystal Growth
- Solidification Research
- Fluids & Combustion
- Containerless Processing
- Middeck-Class Payloads with SAMS SSF
- Biotechnology
- SSSP-Provided Microgravity Glovebox

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* SAMS SSF is Station-unique hardware, not transition hardware
- Evaluate the effects of gravity on the growth of protein crystals
- Study physics/dynamics of macromolecular crystal growth
- Support biotechnology research by growing high quality macromolecular protein crystals which can be used for x-ray crystallography
Advanced Protein Crystal Growth (APCG)
Payload Description (1997 - 1998)

- Power: 0.5 kW nominal/1 kW peak
- Mass: 300 kg
- Volume: 1 rack

**TRANSITION HARDWARE**
2 Thermal Enclosure System (TES) units with crystal growth apparatus
SSFP provides adapter hardware, integration

- APCG plans to accommodate second generation crystal growth hardware in TES units
  - Vapor Diffusion Apparatus
  - Thermally-controlled batch process
  - Liquid-liquid diffusion
  - Dynamically-controlled systems
- Automated experiment initiation and deactivation

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- Power: 2.1 kW nominal/2.4 kW peak
- Mass: 616 kg
- Volume: 1 rack

**Space Station-unique hardware**
- Advanced thermal enclosures
- Enhanced diagnostic systems with imaging capability

- Third generation protein crystal growth hardware
  - May accommodate a larger number of experiments than APCG by using advanced thermal enclosures
  - Can accommodate current TES, new thermal enclosures, or PI-supplied thermal enclosures for long-duration crystal growth, and enhanced diagnostics
  - Automated experiment initiation and deactivation
• Gain understanding of the mechanisms which correlate directional solidification parameters and materials properties for various technologically important materials

• Explore potential for utilization of low gravity environment to develop unique materials or materials structures which have unique, crafted properties

• Measure thermophysical properties of materials
Space Station Furnace Facility/Crystal Growth
Furnace Payload Description (1997 - 1998)

- Power: 2.0 kW nominal/4.0 kW peak
- Mass: 1050 kg
- Volume: 2 racks
  1 Rack - Core: Space Station-unique controls, power conditioning and diagnostics
  1 Rack: CGF furnace
  - Pressure vessel with flexible glovebox
  - Reconfigurable furnace module
  - Furnace translation mechanism
  - Automated sample exchange mechanism (up to six samples)

- Gradient zone thickness can be optimized before launch, and a heat extraction plate can be included to obtain steeper gradients
- Interface demarcation will be available by mechanical and current pulsing

Space Station Furnace Facility (SSFF)

- Power: 6.5 kW nominal/9.0 kW peak
- Mass: 1,350 kg
- Volume: 3 racks
  1 Rack - Core: Space Station-unique controls, power conditioning and diagnostics
  1 Rack: Furnace Module 1
  1 Rack: Furnace Module 2

- Furnace Modules -- to be determined from NASA Research Announcement/Announcement for Opportunity (NRA/AO) selection -- first PI selections in August 1992
- Modules being considered
  - Upgraded programmable Multi-Zone Furnace (used for planning purposes)
  - Transparent Furnace
  - Bridgman with Quench
  - Float-Zone Crystal Growth Furnace
• Provide better understanding of fundamental theories of combustion processes and phenomena, such as:
  - Premixed gaseous fuel combustion
  - Laminar and turbulent diffusion flames
  - Flame spreading and smoldering with solid fuels
  - Flame spreading over liquid pools
  - Effectiveness of fire extinguishing techniques
  - Droplet, particle, and spray combustion
  - Metals combustion

• Provide scientific and engineering data for a variety of combustion related applications, such as spacecraft fire safety
Advanced Combustion Middeck Payload

- Power 120 W
- Mass 400 kg
- Volume 4 middeck lockers

- A CoDR was held in December 1991
- Will have the capability to do multiple experiment samples intensified video for low luminosity
- Studying the capability for chamber atmosphere clean-up

Modular Combustion Facility (MCF)
Payload Description (1998 - 2000)

- Power 1.5 kW nominal/2.3 kW peak
- Mass 1,400 kg
- Volume 2 racks

TRANSITION HARDWARE
1 Rack - Core Shares a common core with the fluids module
1 Rack Module 1 - Combustion experiment rack

- The combustion experiment rack will house a generic combustion chamber with investigation-specific equipment
  - Nozzles for burning of gases
  - Sample holders for solid fuels experiment
- The combustion chamber will have ports to accommodate different modular diagnostics systems:
  - CCD video system
  - Infrared imager
  - Schlieren imaging system
  - Temperature measuring probes
  - Gas sampling probes
Modular Combustion Facility (MCF)
Payload Description (2001+)

- Power: 5 kW nominal/7.1 kW peak
- Mass: 1,400 kg
- Volume: 2 racks

STATION-UNIQUE HARDWARE

1 Rack - Core: Core 2 shared with fluid modules
1 Rack - Module 2: combustion experiment rack

- Module 2 to be determined from NRA/AO selection
- Two candidate experiment racks under study
  - Quiescent Combustion Chamber
  - Low-Speed Combustion Tunnel

Fluid Physics and Dynamics
Science Utilization

- Provide advances in theories of fluid physics
- Provide improvements in thermophysical property measurement
- Provide scientific and engineering data related to fluids-related applications and systems
- Experiments may cover a broad area of interest:
  - Isothermal-isosolutal capillary phenomena
  - Capillary phenomena with thermal/solutal gradients
  - Thermal solutal convection and diffusive flows
  - First order phase transitions in a static fluid
  - Multi-phase flow
Fluids Program Evolution

**FES (1985, 1992)**
- Fluid Experiment System
- Spacelab, multi-user

- Surface Tension
- Driven Convection
- Experiment
- Spacelab, PI-specific

- Pool Boiling Experiment
- Get-away special payload, PI specific

**AFM (1999)**
- Advanced Fluids Module for SSF
- Multi-user module added to Fluids/Combustion core facility

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Fluid Physics Dynamics Facility (FPDF)

**Payload Description (1999+)**

- **Power**
  - Fluids Module 1:
    - 2.0 kW nominal/3.0 kW peak
  - Fluids Module 2:
    - 5.9 kW nominal/9.5 kW peak

- **Mass**
  - 700 kg

- **Volume**
  - 1 rack

  Core shared with MCF

  1 Rack
  - Fluids Module-1 (1999)
  - Changed out for Fluids Module-2 (2000)

- **Modules 1 and 2** – to be determined by AO/NRA selection

- **Two candidate experiment racks under study**
  - Support dynamic fluid experiments in a multi-phase apparatus
  - Vibration isolation containment enclosure for sealed-cell experiments

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• Accommodate experiments requiring the positioning and manipulation of materials without physical contact with container walls

• Conduct research on properties and phenomena that on Earth are seriously affected by container contamination, container-generated nucleations, and gravity effects
Modular Containerless Processing Facility (MCPF) Payload Description (under review)

- **Power**: 2.5 kW nominal/3.0 kW peak
- **Mass**: 700 kg
- **Volume**: 1 rack

Sample positioning devices
Diagnostics and control

- Levitation modules to position the sample may be electrostatic, electromagnetic, acoustic fields, or a hybrid combination
- Gain understanding in vast area of physical sciences ranging from the behavior of liquid drops in space, the measurement of thermophysical properties of materials, and the characterization of metals, glasses, and ceramics heated to temperatures up to 2700°C

Study cell function and differentiation in a low mechanical stress environment

Culture end-differentiated tissue models for studies of genetic regulations
Biotechnology Program Evolution

**IEE (1984, 1988)**
- Isoelectric Focusing
- Middeck, PI-specific

- Phase Partitioning Experiment
- Middeck, PI-specific

**CEES (1982-1985)**
- Continuous Flow Electrophoresis System
- Middeck

**Biosector (DSO in 1991)**
- Rotating wall cell culturing system
- Middeck, multi-user
- Awaiting results of 1991
- Biotechnology NRA to determine future flight development

**BTF (1997)**
- Biotechnology Facility for SSF
- Host Facility for future investigations in:
  - Cell culturing
  - Cell separations
  - Future areas of Biotechnology

**Biotechnology Facility Payload Description (1997+)**

- **Power**: TBD kW nominal and peak
- **Mass**: 700 kg
- **Data**: TBD Kbits/sec
- **Volume**: 1 rack

- **The BTF will accommodate a series of PI-developed, self-contained biotechnology experiments. BTF "services" will include power conditioning and distribution, video and data processing, and basic gases and fluids.**

- **Concept may serve as the basis for a Small and Rapid-Response (SRR) Payload (1999)**
"Middeck Class" Payloads (1997+)

- **Power**: TBD kW nominal and peak
- **Mass**: TBD
- **Data**: TBD Kbits/sec
- **Volume**: 2 racks

**TRANSITION HARDWARE**
Middeck-class experiments
SSFP provides adapter hardware, integration

- The SSFP-provided Middeck Class Payload Adapter (MDC) will host a series of small to moderate-scale microgravity experiments by providing an interface that emulates the Shuttle middeck
  
  Experiments in Fluids and Transport Phenomena, Combustion, Materials Science

- MDC Accommodations will be similar to those provided by the SSFP interface hardware used for the APCG Transition Payload

SSFP-Provided Microgravity Glovebox (1997+)

- **Power**: TBD kW nominal and peak
- **Mass**: 700 kg
- **Data**: TBD Kbits/sec
- **Volume**: 1 rack

- The SSFP-Provided Materials Science Glovebox (MSG) provides an enclosed work space isolated from the SSF ambient environment for handling microgravity science samples and hardware
- The MSG will accommodate a series of small-scale microgravity science experiments and technology demonstrations
- MSG services will include video and film cameras with appropriate lighting, temperature control and heat rejection in the work volume, power outlets for use by experiments and apparatus for recovering fluid spills
Utilization Flights

- All Microgravity Science and Applications Division (MSAD) payloads plan to operate during utilization flights
- Some operations will be very similar to Spacelab
  - High-speed film cameras for data storage
  - Discipline-emphasis crew skills
- Operations unlike Spacelab
  - On-orbit rack changeout
  - Logistics/resupply (gases), sample harvesting, and changeout for return
  - Experiment set up for ground-tended runs

Unmanned Operations

- All MSAD payloads except combustion plan to operate during ground-tended operations
- Payloads will require uplink communications
  - For initiating run sequences
  - Power on/off
  - Restart experiment run
- Payloads will require downlink
  - Monitoring experiment runs
  - Health and safety
  - Quick-look analysis
Operational Intent of MSAD-MTC

- Two to three 16-day utilization flights each year
- Operation of facilities during utilization flights
  - Experiments requiring crew interaction
  - Shorter duration experiments
  - Experiments that are less sensitive to "noisy" acceleration environment
- Operations between utilization flights (ground-tended periods)
  - Experiments that can be controlled remotely and/or automated
  - Longer duration experiments
  - Experiments requiring a pristine environment
- Operations during assembly flights
  - Conducted on a non-interference basis
  - May be limited to changing out samples and setting up experiments to be initiated later

Operational Intent of MSAD-PMC

- Payloads requiring crew interactions
- Automated payloads utilizing telescience methods
- Crew time is a limited resource
- Science return from MSAD payloads will begin in 1997 after launch of the U.S. Laboratory and will continue through 2000+
  - MSAD plans to conduct a broad range of experiments during the unmanned periods prior to PMC, during utilization flights, and PMC and beyond on SSF

- Science operations conducted during the utilization flights will be similar to Spacelab flights except for the added tasks of collecting and securing of samples, experiment setup for unmanned runs, and rack/module equipment changeout

- Unmanned operations will require automation of payloads and telescience but minimal two-way communications between MSAD payloads and the ground is intended

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Microgravity Science and Applications Program Summary

- Active, growing, diverse program
- Areas of research
  - Biotechnology
  - Combustion
  - Fluids Science
  - Fundamental Physics
  - Materials Science
- Continuing to find new experimental possibilities
  - Encouraging science community to participate
  - Soliciting science proposals through NRA's
  - Facilitating their development
- Collaborating with the international science community
  - Sharing use of facilities
- Looking forward to an exciting decade in microgravity research
Back Up Charts

Science Planning Process

- Community involvement in the program
  - Four DWG's plus Microgravity Subcommittee to Space Science and Applications Advisory Committee (SSAAC)

- National Academy of Sciences
  - Microgravity Science Committee of the Space Studies Board
    - Established in 1988
    - First meeting in 1990
  - Development of long-term strategy for microgravity sciences

- Integrate microgravity initiatives into OSSA program
  - SSAAC review and advice
  - OSSA Strategic Plan
SSB Committee on Microgravity Research
Membership List

**Chairperson**
William A. Sirlgnano (6/94)
Dean, School of Engineering
University of California at Irvine
[Combustion]

Franklin D. Lemkey (6/92)
Materials Technology Laboratory
United Technologies Research Center
[Metals]

Thomas A. Steitz (6/94)
Department of Molecular Biophysics and Biochemistry
Yale University
[Protein Crystallography]

Richard C. Hart
Space Studies Board
National Academy of Science

Simon Ostrach (6/94)
Department of Mechanical and Aerospace Engineering
Case Western Reserve University
[Fluid Flow and Transfer]

Warren C. Strahle (6/94)
School of Aerospace Engineering
Georgia Institute of Technology
[Combustion]

Franklin D. Lemkey (6/94)
Materials Technology Laboratory
United Technologies Research Center
[Metals]

Robert A. Brown (6/92)
Head of Chemical Engineering
Mass Institute of Technology
[Fluid Dynamics & Elec Mais Model]

Morton B. Panish (6/94)
Distinguished Member of the Technical Staff
AT&T Bell Laboratories
[Electronic Materials]

Julia R. Weertman (6/94)
Department of Materials Science and Engineering
Northwestern University
[Metals]

Martin E. Glicksman (6/94)
Department of Materials Science
Rensselaer Polytechnic University
[Metals]

John D. Reppy (6/94)
Laboratory of Atomic and Solid State Physics
Cornell University
[Physics]

[Biotechnology]

Membership of Microgravity Science and Applications Subcommittee (MSAS)

**Chair:**
Dudley Saville
Chemical Engineering Department
Princeton University

**Exec. Secretary:**
Roger Crouch
NASA Headquarters
MSAD Chief Scientist

| MEMBERS |
|------------------|------------------|
| Gary Gilliland | National Institute for Standards and Technology Center for Advanced Research in Biotechnology Biotechnology DWG Chair |
| Gerard Faeth | Dept. Aerospace Engineering University of Michigan Combustion DWG Chair |
| Stephen H. Davis | Department of Engineering Sciences and Applied Mathematics Northwestern University Fluids & Transport DWG Chair |
| John Perepezo | Department of Materials Science and Engineering University of Wisconsin Materials Science DWG Chair |
| Simon Ostrach | Department of Mechanical and Aerospace Engineering Case Western Reserve University |
| Alexander Mcpherson | Department of Biochemistry University of California |
## Members and Affiliations (7/21/92)

<table>
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<tr>
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<tr>
<td><strong>Chairman:</strong> Dr. Charles A. Fuller</td>
<td>University of California, Davis</td>
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<td>Executive Secretary: Dr. Edmond M. Reeves</td>
<td>NASA Headquarters</td>
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<tr>
<td>Dr. Charles E. Bugg</td>
<td>University of Alabama at Birmingham</td>
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<tr>
<td>Dr. Robert J. Bayuzick</td>
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<td>Dr. Benton C. Clark</td>
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<td>Dr. David Robertson</td>
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<tr>
<td>Dr. Marc E. Tischler</td>
<td>University of Arizona</td>
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### Discipline Working Groups

- **Biotechnology**
  - Chair: Dr. Gary Gilliland (NIST)
  - Vice-Chair: Dan Carter (MSFC)

- **Combustion**
  - Chair: Dr. Gerard Faeth (University of Michigan)
  - Vice-Chair: Kurt Sacksteder (LeRC)

- **Fluids and Transport**
  - Chair: Stephen H. Davis (Northwestern University)
  - Vice-Chair: Bob Thomson (LeRC)

- **Materials Science**
  - Chair: John Perepezko (University of Wisconsin)
  - Vice-Chair: Frank Szofran (MSFC)
### Combustion Discipline Working Group

**Prof. Gerard Faeth (Chair)**  
Dept. of Aerospace Engineering  
University of Michigan

**Mr. Kurt Sacksteder (Vice-Chair)**  
NASA Lewis Research Center

**Dr. Robert Altenkirch**  
College of Engineering  
Mississippi State University

**Prof. Robert Santoro**  
Mechanical Engineering Dept.  
Pennsylvania State University

**Dr. Raymond Friedman**  
Factory Mutual Research

**Prof. Mitchell Smooke**  
Dept. of Mechanical Engineering  
Yale University

**Prof. Jack Howard**  
Dept. of Chemical Engineering  
Massachusetts Institute of Technology

**Prof. Forman Williams**  
Applied Mechanical and Engineering Science Dept.  
University of California at San Diego

**Prof. C. K. Law**  
Dept. of Mechanical and Aerospace Engineering  
Princeton University

**Prof. Robert Santoro**  
Mechanical Engineering Dept.  
Pennsylvania State University

**ESD Representative**  
Dr. I. Gokalp  
CNRS - Laboratoire de Combustion et Systemes Reactifs, Orleans

### Biotechnology Discipline Working Group

**Dr. Gary Gilliland (Chair)**  
Center for Advanced Research in Biotechnology  
National Institute of Standards and Technology

**Dr. Daniel Carter (Vice-Chair)**  
NASA Marshall Space Flight Center

**Dr. Colette Freeman**  
Division of Cancer Biology, Diagnosis, and Centers  
National Cancer Institute

**Dr. F. L. Suddath**  
Vice-President for Information Technology  
Georgia Institute of Technology

**Dr. Scott Power**  
Director of Biochemistry  
Genencor International

**Dr. Patricia Weber**  
Central Research and Development Dept.  
Dupont-Merck Pharmaceutical Company

**Dr. Frank Putnam**  
Dept. of Biology  
Indiana University

**ESD Representative**  
Prof. P. G. Pighetti  
Università di Milano, Departmento di Scienze e Technologie Biomediche, Sez. Chemica Organica, Milano

**Prof. Lola Reid**  
Dept. of Molecular Pharmacology  
Albert Einstein College of Medicine
Membership of Discipline Working Groups (DWG's)

DWG
= 8 - 12 members

- Chair
- Ex Officio Member
- Vice-Chairperson
- 4 Members
- Member

Unaffiliated (desired)
Discipline Program Scientist
Center Scientist
Principal Investigator(s)
(2 maximum)
Industry
Academia
Other Government

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SPACE STATION FREEDOM COMBUSTION RESEARCH

Presented by G.M. Faeth
Department of Aerospace Engineering
The University of Michigan

ABSTRACT

Extended operations in microgravity, on board spacecraft like Space Station Freedom, provide both unusual opportunities and unusual challenges for combustion science. On the one hand, eliminating the intrusion of buoyancy provides a valuable new perspective for fundamental studies of combustion phenomena. On the other hand, however, the absence of buoyancy creates new hazards of fires and explosions that must be understood to assure safe manned space activities. These considerations—and the relevance of combustion science to problems of pollutants, energy utilization, waste incineration, power and propulsion systems, and fire and explosion hazards, among others—provide strong motivation for microgravity combustion research.

The intrusion of buoyancy is a greater impediment to fundamental combustion studies than to most other areas of science. Combustion intrinsically heats gases with the resulting buoyant motion at normal gravity either preventing or vastly complicating measurements. Perversely, this limitation is most evident for fundamental laboratory experiments; few practical combustion phenomena are significantly affected by buoyancy. Thus, we have never observed the most fundamental combustion phenomena—laminar premixed and diffusion flames, heterogeneous flames of particles and surfaces, low-speed turbulent flames, etc.—without substantial buoyant disturbances. This precludes rational merging of theory, where buoyancy is of little interest, and experiments, that always are contaminated by buoyancy, which is the traditional path for developing most areas of science. The current microgravity combustion program seeks to rectify this deficiency using both ground-based and space-based facilities, with experiments involving space-based facilities including: laminar premixed flames, soot processes in laminar jet diffusion flames, structure of laminar and turbulent jet diffusion flames, solid surface combustion, one-dimensional smoldering, ignition and flame spread of liquids, drop combustion, and quenching of panicle-air flames.

Unfortunately, the same features that make microgravity attractive for fundamental combustion experiments, introduce new fire and explosion hazards that have no counterpart on earth. For example, microgravity can cause broader flammability limits, novel regimes of flame spread, enhanced effects of flame radiation, slower fire detector response, and enhanced combustion upon injecting fire extinguishing agents, among others. On the other hand, spacecraft provide an opportunity to use "fire-safe" atmospheres due to their controlled environment. Investigation of these problems is just beginning, with specific fire safety experiments supplementing the space-based fundamental experiments listed earlier; thus, much remains to be done to develop an adequate technology base for fire and explosion safety considerations for spacecraft.
SPACE STATION FREEDOM
COMBUSTION RESEARCH

G. M. Faeth
Department of Aerospace Engineering
The University of Michigan
Ann Arbor, Michigan

INTRODUCTION
RELEVANCE OF COMBUSTION SCIENCE

SEVERAL CONCERNS MOTIVATE FUNDAMENTAL COMBUSTION RESEARCH:

- Combustion-generated pollutants are re-emerging as a major problem.
- New combustion technologies are needed for effective energy utilization.
- Municipal and hazardous waste incineration is needed to replace landfills and storage.
- Fire and explosion hazards remain a source of excessive injuries, and loss of life and property on earth.
- New combustion technologies are needed for advanced aircraft and spacecraft propulsion systems.
- Current understanding of fire and explosion hazards in spacecraft is very limited.

OPPORTUNITIES AND CHALLENGES

THE MICROGRAVITY ENVIRONMENT OF SPACECRAFT OFFERS BOTH OPPORTUNITIES AND CHALLENGES TO COMBUSTION SCIENCE:

- The implications of microgravity experimentation are as important as the development of computers and optical diagnostics.
- Increased activity in space implies new fire and explosion hazards beyond our earth-bound technology base.
BUOYANCY LIMITATIONS
OF MOTIONLESS FLAMES

BUOYANCY IS AN INTRUSION BECAUSE FEW PRACTICAL FLAMES ARE BUOYANT:

- Buoyant/molecular transport is given by the Grashof number:
  \[ Gr = \frac{\Delta \rho g L^3}{(\rho v^2)} \]

- For flames, \( \Delta \rho / \rho \approx 1 \), while \( Gr \ll 1 \) for negligible buoyancy.

- At atmospheric pressure, this implies:
  \( L \ll \text{Order (100 \, \mu m)} \)

EXPERIMENTS ON SUCH SCALES CANNOT BE RESOLVED BY EXISTING, OR ANTICIPATED, COMBUSTION INSTRUMENTATION.
BUOYANCY LIMITATIONS
OF PROPAGATING FLAMES

THE CRITERION FOR NEGligible BUOYANCY EFFECTS DIFFERS FOR
PROPAGATING FLAMES:

• Buoyant/propagation convection
  is given by the Richardson number:

\[ Re = \frac{\Delta \rho g L}{(\rho u^2)} \]

• For flames, \( \Delta \rho/\rho \sim 1, L > 10 \text{ mm} \)
  while \( Ri \ll 1 \) for negligible buoyancy

• This implies:

\[ u > \text{Order (1 m/s)}. \]

THIS IS COMPARABLE TO MAXIMUM BURNING VELOCITIES BUT
PRECLUDES STUDIES NEAR FLAMMABILITY LIMITS.

FLAMMABILITY LIMITS

BUOYANCY HAS THWARTED ATTEMPTS TO UNDERSTAND
FLAMMABILITY LIMITS — AN IMPORTANT FUNDAMENTAL
PROPERTY OF FLAMES:

Lean Flammability Limits
(% Fuel in Air)\(^a\)

<table>
<thead>
<tr>
<th>Config.</th>
<th>Methane</th>
<th>Propane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downward</td>
<td>5.85</td>
<td>2.20</td>
</tr>
<tr>
<td>Upward</td>
<td>5.25</td>
<td>2.15</td>
</tr>
<tr>
<td>Microgravity</td>
<td>5.25</td>
<td>2.06</td>
</tr>
</tbody>
</table>

\(^a\)From Strehlow et al. (1986)

• Upward propagation exhibits obvious instabilities but
  buoyancy affects all flame orientations.

• Lean limits generally are lower in microgravity than normal
  gravity for hydrocarbons, except for methane.
FLAME SPREAD ALONG SOLID SURFACES

FLAME SPREAD ALONG SURFACES IS AFFECTED BY BUOYANCY, AMBIENT OXYGEN CONCENTRATION AND OPPOSING FLOW ALONG THE SURFACE:

- Microgravity conditions allow a low velocity regime to be reached that is inaccessible at normal gravity.
- Spread rates are highest and flammability limits are lowest in this low velocity regime.

NOTABLY, THE LOW VELOCITY REGIME IS TYPICAL OF NORMAL VENTILATION CONDITIONS ON SPACECRAFT.

BUOYANCY LIMITATIONS OF CONVETING FLAMES

BUOYANCY PREVENTS STUDY OF LOW REYNOLDS NUMBER FLAMES:

- The characteristic Reynolds number of a forced flame is:

\[ \text{Re} = \frac{Lu}{v} = (\text{Gr}/\text{Ri})^{1/2} \]

- For \( L \) ca. 10 mm, \( \text{Gr} = \text{Order } (10^3) \) while \( \text{Ri} < \text{Order } (10^{-1}) \) for negligible buoyancy.

- This implies:

\[ \text{Re} > \text{Order } (10^2) \]

THUS, THE STOKES FLOW REGIME (\( \text{Re} < 1 \)) IS NOT ACCESSIBLE, WHILE THE LARGE \( \text{Re} \) LIMITS SPATIAL RESOLUTION AND CAUSES TRANSITION TO TURBULENCE.
CONVEXTIVE DROP COMBUSTION

BUOYANCY HAS PREVENTED RESOLUTION OF EFFECTS OF CONVECTION ON DROP BURNING RATES — AN IMPORTANT HETEROGENEOUS FLAME:

- Exact theories are limited to low Reynolds numbers.
- Buoyancy prevents reaching low Reynolds numbers for experimentation.
- Deformation and internal circulation intrude at accessible Reynolds numbers.

THUS, CONTROVERSIES ABOUT CONVEXTIVE EFFECTS CONTINUE; ONLY EXPERIMENTS IN MICROGRAVITY CAN RESOLVE THIS ISSUE.

TURBULENT COMBUSTION

TURBULENT COMBUSTION IS THE FOREMOST UNRESOLVED PROBLEM OF COMBUSTION SCIENCE:

- Numerical simulations are limited to low Reynolds number conditions.
- Buoyancy immediately accelerates combusting flows to high Reynolds numbers.
- Computer development rates imply 50-100 years before feasible experiments can be simulated.

EXPERIMENTS IN MICROGRAVITY CAN ACCOMPLISH THE MERGER MUCH SOONER AND OFFER VALUABLE INSIGHTS OF THEIR OWN.
COMBUSTION SCIENCE CHALLENGES

PERSPECTIVES ON SPACECRAFT FIRE SAFETY

"FIRE IS ONE OF THE MOST FEARED HAZARDS IN SPACECRAFT."

"...STRICT LIMITATIONS ON ACCEPTABLE MATERIALS, AND STRINGENT HIGH-SAFETY-FACTOR OPERATING PROCEDURES ALL CAN RESTRAIN USEFUL ACTIVITIES IN SPACE MISSIONS."

"PRESENT SPACECRAFT FIRE-SAFETY PROCEDURES ARE ADEQUATE, TO THE EXTENT OF THE LIMITED KNOWLEDGE OF FIRE BEHAVIOR IN THE MILIEU OF SPACE ... FUTURE SPACECRAFT CONCEPTS, HOWEVER, WILL MAKE MORE DEMANDS ON FIRE SAFETY."

R. Friedman and K. R. Sacksteder
NASA/LeRC, 1988
EFFECTS OF MICROGRAVITY ON FLAMES

FIRE HAZARDS IN MICROGRAVITY DIFFER FROM OUR EARTH-BOUND EXPERIENCE:

- Flammability limits and flame spread rates are not the same, and can be less conservative.
- Flame volumes are much larger, and flame radiation is more dominant, if forced flows are absent.
- Limited space enhances problems of smoldering fires whose properties are not understood in microgravity.
- The response of fire detectors is slower, and the effect of fire extinguishing agents is modified.
- Aerosols do not settle, yielding conditions having no counterpart on earth, and greater fire hazards.

SPACE STATION FREEDOM
FLOW LOOP FACILITY

THIS FACILITY IS DESIGNED FOR FLAMMABILITY STUDIES WITH VARIABLE FORCED VELOCITIES:
FIRE-SAFE ATMOSPHERES

- Atmospheres that support life but not combustion are known, and are used successfully for underwater systems.

- Thus, fire hazards would be left behind on earth if the same approach could be developed for spacecraft.

- This is not feasible — near term — due to system complications and uncertainties of flame properties and human factors.

- The implications of fire-safe and inerting atmospheres are enormous; defining them should have high priority.

SUMMARY
CURRENT MICROGRAVITY COMBUSTION SCIENCE
FLIGHT PROGRAM

<table>
<thead>
<tr>
<th>Title</th>
<th>Investigator</th>
<th>Affiliation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid Surface Combustion</td>
<td>R.A. Altenkirch</td>
<td>Miss. State U.</td>
</tr>
<tr>
<td>One-Dimensional Smoldering</td>
<td>A.C. Fernandez-Pello</td>
<td>UC-Berkeley</td>
</tr>
<tr>
<td>Soot Processes In Jet Flames</td>
<td>G.M. Faeth</td>
<td>U/Michigan</td>
</tr>
<tr>
<td>Laminar &amp; Turbulent Jet Flames</td>
<td>M.Y. Bahadori</td>
<td>SAIC</td>
</tr>
<tr>
<td>Laminar Flames: Limits</td>
<td>P.D. Ronney</td>
<td>Princeton U.</td>
</tr>
<tr>
<td>Liquid Pool Flames</td>
<td>H. D. Ross</td>
<td>NASA/LeRC</td>
</tr>
<tr>
<td>Combustion of Pure Fuel Drops</td>
<td>F.A. Williams</td>
<td>UC-San Diego</td>
</tr>
<tr>
<td>Combustion of Blended Drops</td>
<td>A. Gökalp</td>
<td>CNES</td>
</tr>
<tr>
<td>Dust-Air Mixture Flames</td>
<td>J.H.S. Lee</td>
<td>McGill U.</td>
</tr>
</tbody>
</table>

aThe glove-box facility on USML-2 also has been used for preliminary tests of flame spread, smoldering and liquid combustion.
bFlown on the Space Shuttle.

SUMMARY

- Gravity has impeded fundamental understanding of combustion more than most areas of science; access to microgravity should yield major breakthroughs.

- Flames in microgravity are very different from our earth-bound experience; rational safety considerations for spacecraft require an improved technology base.

- Fire-safe atmospheres could permanently eliminate fire hazards from future spacecraft; this interdisciplinary research problem merits high priority.
MICROGRAVITY FLUID PHYSICS RESEARCH IN THE SPACE STATION FREEDOM ERA

Presented by Bradley M. Carpenter
Office of Space Science and Application
NASA Headquarters

ABSTRACT

Microgravity fluid physics covers an exciting range of established and potential fields of scientific research. Areas in which the Microgravity Science and Applications Division of NASA’s Office of Space Science and Applications is currently supporting research include: multiphase flow and phase change heat transfer, behavior of granular media and colloids; and interface dynamics, morphological stability, and contact line phenomena. As they contribute to our knowledge of fluid behavior, advances in these areas will enhance our understanding of materials processing on Earth and in space, and will contribute to technologies as diverse as chemical extraction, the prediction of soil behavior in earthquakes, and the production of oil reservoirs.

NASA’s primary platform for research in microgravity fluid physics will soon be the Fluid Physics/Dynamics Facility on Space Station Freedom. This facility shares a rack for control and utilities with the Modular Combustion Facility, and has one rack for experiment-unique instruments. It is planned to change out the content of the experiment-unique rack at intervals on the order of one year. In order to obtain a maximum return on the operation of the facility during these intervals, the research community must carefully plan and coordinate an effort that brings the efforts of many investigators to bear on problems of particular importance. NASA is currently working with the community to identify research areas in which microgravity can make a unique and valuable contribution, and to build a balanced program of research around these areas or thrusts. Selections will soon be made from our first solicitation for research in fluid dynamics and transport phenomena. Additional solicitations will be released in the future. These solicitations will build the research community that will make Space Station Freedom a catalyst for scientific and technological discovery, and offer U.S. scientists in many disciplines a unique opportunity to participate in space science.
Microgravity Fluid Physics Research in the Space Station Freedom Era

Presentation to the Space Station Freedom Utilization Conference
5 August 1992

Bradley M. Carpenter
Program Scientist
Microgravity Science and Applications Division

Focus Areas for Microgravity Fluid Physics Research:
• Multiphase Flow and Heat Transfer
• Interface Dynamics
• Complex Fluids

Applications of Fluid Physics Research:
• Materials Processing
• Fluids Engineering and Space Fluids Management
• Geotechnical and Environmental Engineering
Space Station Research: The Fluid Physics/Dynamics Facility

- Currently planned as part of a three-rack complex with the Modular Combustion Facility
- Core rack shared with the Modular Combustion Facility provides utilities, control, and data management support
- One rack hosts experiment-specific instrumentation
- Maximizing utilization of instrument capabilities within operational increments requires focused and coordinated research activities


- Space research opportunities are framed by instrument development and operational constraints
- In order to maximize the value of our space resources, we must build a coherent program from ground-based activities to instrument capabilities
- Development of working group and workshop recommendations for research priorities begin the process of structuring the research program
- A research solicitation released in 1991 identified six potential thrust areas for research in fluid dynamics and transport phenomena. 207 proposals were submitted in response. The 40-50 selected proposals will form the first generation of an evolving program

- 1991 Thrust Areas: Capillary Phenomena
  Multiphase Flow and Heat Transfer
  Diffusive Transport
  Magneto/Electrohydrodynamics
  Colloids and Nucleation Phenomena
  Solid-Fluid Interface Dynamics
Opportunities for Microgravity Fluid Physics Research

- Research solicitations for ground-based research and flight experiments in fluid physics (NASA Research Announcements, NRA's) planned for calendar 1993, 1996, 1999

- NRA's for limited ground-based support open to the entire microgravity program will be released annually beginning in early 1993

- Flight experiment concepts are normally developed through extensive ground-based research, often using aircraft, drop tubes, or other short-duration facilities

- Building a comprehensive program of ground-based research to provide candidates for flight and to support planned and potential flight experiments has high priority
MATERIALS SCIENCE RESEARCH IN MICROGRAVITY

Presented by Professor John H. Perepezko
Department of Materials Science and Engineering
University of Wisconsin-Madison

ABSTRACT

There are several important attributes of an extended duration microgravity environment that offer a new dimension in the control of the microstructure, processing and properties of materials. First, when gravitational effects are minimized, buoyancy driven convection flows are also minimized. The flows due to density differences, brought about either by composition or temperature gradients will then be reduced or eliminated to permit a more precise control of the temperature and the composition of a melt which is critical in achieving high quality crystal growth of electronic materials or alloy structures. Secondly, body force effects such as sedimentation, hydrostatic pressure and deformation are similarly reduced. These effects may interfere with attempts to produce uniformly dispersed or aligned second phases during melt solidification. Thirdly, operating in a microgravity environment will facilitate the containerless processing of melts to eliminate the limitations of containment for reactive melts. The noncontacting forces such as those developed from electromagnet, electrostatic or acoustic fields can be used to position samples. With this mode of operation, contamination can be minimized to enable the study of reactive melts and to eliminate extraneous crystal nucleation so that novel crystalline structures and new glass compositions may be produced. In order to take advantage of the microgravity environment for materials research it has become clear that reliable processing models based on a sound ground based experimental experience and an established thermophysical property data base are essential.
Materials Science Research in Microgravity

Professor John H. Perepezko
Department of Materials Science and Engineering
University of Wisconsin-Madison
1509 University Avenue
Madison, WI 53706

Space Station Freedom Utilization Conference
Huntsville, Alabama

August 3-6, 1992

MATERIALS SCIENCE DISCIPLINE

Goals

• Develop the basic understanding of relationships between microstructure and properties of materials during microgravity processing.

• Apply process modeling and advanced processing concepts to achieve designed microstructures.

Objectives

• Utilize the microgravity environment to advance the understanding of materials processing, including phase transformations during solidification and deposition, transport phenomena and structure-property relationships.
Microgravity Environment | Materials Response
---|---
- Buoyancy Driven Convection Flows Minimized | Precise Temperature and Composition Control for High Quality Crystals
- Body Force Effects Minimized | Uniform Spacing and Alignment in Multiphase Materials
- Containerless Melt Processing | Eliminate Contamination and Nucleation Due to Containment
- Interfacial Phenomena | Wetting and Surface Energy Driven Flows

Benchmark Materials

Priorities

**Technological Applications**

- Containerless Processing
- Directional Solidification/Crystal Growth
- Casting

**Science Knowledge Base**

1. Solidification Kinetics and Undercooling
2. Microstructural Morphology/Prediction
3. Process Analysis and Modeling
4. Interfacial Phenomena

**Critical Support Base**

- Ground based experience
- Thermophysical property data
Research Areas

- Solidification Kinetics and Undercooling
  - Nucleation
  - Undercooling
  - Metastable Phase Development
  - Competitive Growth
  - Microstructural Transitions
  - Glass Formation

- Microstructural Morphology/Prediction
  - Plane Front Solidification
    > Single Crystals
    > Aligned Composites
    > Phase Spacing
  - Interface Instability
    > Cells
    > Dendrites
    > Segregation
  - Microstructural Scale
    > Coarsening/Coalescence
    > Scaling Laws

- Process Analysis and Modeling
  > Macrosegregation
  > Heat and Mass Transport Analysis
  > Structure Prediction
- Interfacial Phenomena

  > Surface Energy Driven Flows
    (Temperature or Composition Gradients)
  > Particle Incorporation
  > Wetting Behavior
  > Bubble Formation - Porosity Control
  > Joining Applications
B. SUPERCOOLING (UNDERCOOLING)

\[ \Delta H = \int_{T_2}^{T} C_p dT \]

**TEMP**

**TIME**

COMPOSITION

CD-85-16828
As-Cast

Drop Tube Processed
($\Delta T = 930K$)

Nb-25 at.% Ge Solidification Microstructures

SOLUTE CONCENTRATION
SOLID

LIQUID

DISTANCE ALONG SAMPLE

SOLIDUS

LIQUIDUS

DISTANCE ALONG SAMPLE

BULK MELT

FREEZING POINT OF BULK MELT

SECONDARY ARM SPACING

REJECTED SOLUTE

FREEZING POINT OF SOLUTE RICH MELT

SOLUTE RICH SOLID

MUSHY ZONE

PRIMARY ARM SPACING

MUSHY ZONE
G-L COLUMNAR - EQUIAXED TRANSITION

Possible Mechanisms

Constitutional Supercooling Promotes Nucleation in Center of Ingot

Chill Zone

Equiaxed Dendrites

Mold

Liquid

Convection causes melting or breaking off of dendrite tips.

Dendrites grow with minimal convective disturbance.
MELTING POINT OF PURE A

LIQUID + SOLID $\alpha$

LIQUID

LIQUID + SOLID $\beta$

SOLID $\alpha$ + SOLID $\beta$

SOLIDUS LINE

TEMPERATURE

MELTING POINT OF PURE B

COMPOSITION

PURE A

$C_E$

PURE B
Examples of in situ composites. An electron emitter formed from 0.3 micron tungsten single crystal fibers embedded in a zirconia matrix is shown at the top. A section of a nickel-based superalloy used for turbine blades is shown at the bottom. The matrix material has been etched away to reveal the single crystal tantalum carbide reinforcing fibers that allow the blade to operate for longer times at higher temperatures. Such structures can generally be made on earth only at the eutectic composition. Microgravity offers the possibility of extending the range of compositions to optimize the resulting structure. (Photographs courtesy of General Electric)
Process Analysis and Modeling

- Assess role of individual variables
- Control and Vary Independently Process Parameters
- Reduce Complex Processes to Fundamental Units
- Explore Regimes Unavailable to Experiment
- Design Experiments to Emphasize Phenomena of Interest
- Interpret Results
- Improve Yield from Microgravity Experiments
Solidification Processes

Mushy Zone

Heat Transfer Coefficients
Interface, environment

Heat evolution
Mushy zone model

Material properties

G - 3. SEGREGATION

MACROSEGREGATION

\[ \bar{V} = -K \left( \nabla \rho + \rho_L \bar{g} \right) \]

MICROSEGREGATION

+ ENRICHMENT OF ALLOYING ELEMENTS
- DEPLETION OF ALLOYING ELEMENTS
A-1. DENDRITE COARSENING

[Images of dendrites labeled a, b, c, and d with a scale bar of 0.5 mm]

CD-85-16832
\[ V(\text{mm/s}) \]

\[ G(\text{K/mm}) \]

- Equiaxed dendritic
- Casting
- Fine
- Oriented dendritic
- Oriented cellular
- Coarse
- DS

\[ V = G \frac{D}{A_0} \]

\[ \text{Lamellar spacing } S \ (\text{nm}) \]

\[ \text{Growth rate } (\text{cm/sec}) \]

Slope = -0.5
C-4. THERMAL MIGRATION

TEMPERATURE GRADIENT \[ \frac{dT}{dX} \]

INTERFACIAL TENSION GRADIENT \[ \frac{dy}{dT} \]

FLUID FLOW

FLUID A

DISPERSED PHASE B

DROPLET VELOCITY, \( V \)

G-4. SURFACE TENSION DRIVEN FLOW

ELECTRON BEAM SCAN

ALUMINUM

AI-Cu EUTECTIC BAND

ALUMINUM

CD-85-16838
Thermophysical Properties

- Emissivity, Electrical Conductivity, Optical Properties
- Calorimetry
  - Specific heats
  - Heats of mixing, formation, transformations, ...
- Transport Coefficients
  - thermal conductivity
  - viscosity
  - diffusion constants
- Density Data
- Thermodynamic Modulii
  - thermal expansion coefficients
  - compressibility, etc.
- Vapor Pressures and Activity Coefficients
- Surface Tension/Interfacial Energies

Research Opportunities

- Electrodeposition
- Powder Processing
- Joining
- Novel Materials
- Extraterrestrial Materials
PROTEIN CRYSTAL GROWTH IN MICROGRAVITY

Presented by Daniel Carter
Biophysics Branch
NASA Marshall Space Flight Center

ABSTRACT

The overall scientific goals and rationale for growing protein crystals in microgravity will be discussed. Data on the growth of human serum albumin crystals which were produced during the First International Microgravity Laboratory (IML-1) will be presented. Potential scientific advantages of the utilization of Space Station Freedom will be discussed.
IMPORTANCE:

**Scientific application of crystals**

a. Fundamental importance in molecular biology - understanding how enzymes function etc.

b. Knowledge of accurate atomic structures of proteins of key importance in rational drug design

**Crystal properties and growth processes**

a. Understanding important influences on the growth of high quality protein crystals by using gravity as an experimental variable

b. What properties of the crystals are different, e.g., resolution, defect structure, mosaicity
PROBLEM:
Growth of high quality protein crystals for application in atomic structure determination by x-ray and neutron diffraction

Rationale
a. Reduction of solutal convection
b. Elimination of sedimentation effects

Approach
Vapor diffusion/equilibration method - small multiuser Co-Investigator hardware
BENEFITS/SCIENTIFIC RESULTS

- Several crystal structures have now been refined to significantly higher resolution than previously obtainable by similar ground-based methods.

- Recent success with the longer duration IML-1 mission have produced additional important examples
RELEVANCE TO SPACE STATION

- Protein crystal growth is an experimental science. It will advance at a rate commensurate with number of experiments. Timely human interaction essential to progress.

- Many proteins require growth periods from one to several months.
PROTEIN STUDY POTENTIALS vs. MISSION DURATION
(1025 CANDIDATE PROTEINS)

PROTEIN CRYSTAL GROWTH SAMPLE OPPORTUNITIES
OFFICE OF COMMERCIAL PROGRAMS’ RESEARCH ACTIVITIES
FOR SPACE STATION FREEDOM UTILIZATION

Presented by James A. Fountain
Office of Commercial Programs
NASA Headquarters

ABSTRACT

One of the Objectives of the Office of Commercial Programs (OCP) is to encourage, enable, and help implement space research which meets the needs of the U.S. industrial sector. This is done mainly through seventeen Centers for the Commercial Development of Space (CCDSs) which are located throughout the United States. The CCDSs are composed of members from U.S. companies, universities, and other government agencies. These Centers are presently engaged in industrial research in space using a variety of carriers to reach low Earth orbit. One of the goals is to produce a body of experience and knowledge that will allow U.S. industrial entities to make informed decisions regarding their participation in commercial space endeavors. A total of 32 items of payload hardware have been built to date. These payloads have flown in space a total of 73 times.

The carriers range from the KC-135 parabolic aircraft and expendable launch vehicles to the Space Shuttle. This range of carriers allows the experimenter to evolve payloads in complexity and cost by progressively extending the time in microgravity. They can start with a few seconds in the parabolic aircraft and go to several minutes on the rocket flights, before they progress to the complexities of manned flight on the Shuttle. Next year, two new capabilities will become available: COMET, an expendable-vehicle-launched experiment capsule that can carry experiments aloft for thirty days; and SPACEHAB, a new Shuttle borne module which will greatly add to the capability to accommodate small payloads.

All of these commercial research activities and carrier capabilities are preparing the Office of Commercial Programs to evolve those experiments that prove successful to Space Station Freedom. OCP and the CCDSs are actively involved in Space Station design and utilization planning and have proposed a set of experiments to be launched in 1996 and 1997. These experiments are to be conducted both internal and external to Space Station Freedom and will investigate industrial research topics which range from biotechnology to electronic materials to metallurgy. Some will be designed to make maximum use of the quiescent microgravity conditions in the “ground-tended” phases during the early years of Space Station Freedom operations.
NASA OFFICE OF COMMERCIAL PROGRAMS' RESEARCH ACTIVITIES FOR SPACE STATION FREEDOM

Presented at the

Space Station Freedom Utilization Conference
Session 3: Discipline Perspectives: Microgravity Research and Biotechnology

Von Braun Civic Center
Huntsville, AL

By

James A. Fountain
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Huntsville, AL

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NASA Headquarters
Washington, DC

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OFFICE OF COMMERCIAL PROGRAMS

SPACEx STATION FREEDOM PAYLOAD SPONSORS

- JAPAN - NASDA
- EUROPEAN SPACE AGENCY - ESA
- CANADA - CSA
- UNITED STATES - NASA
  - Office of Commercial Programs - OCP (Code C) - 28%
  - Office of Space Science and Applications - OSSA (Code S) - 52%
  - Office of Aeronautics and Space Technology - OAST (Code R) - 12%
  - Office of Space Flight - OSF (Code M) - 8%
  - Office of Space Systems Development - OSSD (Code D) - 8%

* Shared between OSF and OSSD

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Centers for Commercial Development of Space (CCDS)

HOW DO THEY WORK?

- Schering Plough
  ($, Expertise, Samples)
- Georgia Tech
  (Contracted Research)
- Mississippi State
  (Contracted Research)
- University of Alabama
  at Birmingham CCDS
  Center for Macromolecular
  Crystallography*
  (Research, Management,
   Coordination of Affiliates,
   Interface with NASA)
- NASA OCP
  ($) (Research, Management,
   Coordination of Affiliates,
   Interface with NASA)
- DuPont Merck
  ($, Expertise, Samples)
- Brookhaven National Lab
  (Sample Characterization)
- Eli Lilly
  ($, Expertise, Samples)

* For illustration purposes only. Only 6 of the 34 affiliates are shown.
## Current CCDS Commercial Technologies

### Auburn
- Solar Furnace Satellite
- Crystal Growth of Electronic Materials
- Computational Modeling of Casting Processes

### Battelle
- Solution Crystal Growth
- Polymer Composites
- Float Zone Crystal Growth - CdTe
- Zeolite Crystal Growth
- Doped Non-Linear Optical Substrates
- Investigations into Polymer Membranes

### Bioserve
- Plant Growth Apparatus
- Blood Rheology Experiment
- Generic Biodetection Module
- Autonomous Biomedical Test Apparatus

### Case Western
- Materials Exposure - Basic, Advanced, & Applied

### Clarkson
- Zeolite Crystal Growth
- Low-Temp Solidification
- Liquid Encapsulated Melt Zone
- Directional Solidification - CdTe
- Chemical Vapor Transport - CdTe
- Commercial Solution Growth Facility

### CSTAR
- Cryogenic Fluid Management
- Electric, Chemical Propulsion
- Industrial Laser System Applications

### Florida Atlantic
- Transmission Techniques

### Ohio State
- Remote Sensing & Mapping

### Penn State
- Bioreactor
- Telemetry
- Bioseparations
- Bone Densitometry
- Physiological Systems Experiment
- Light Stimulator & Photon Detector
- Commercial Electrophoresis System

### SpARC
- Autonomous Rendezvous & Docking
- Automated Microgravity Materials Processing

### SREC
- Remote Sensing & Applications

### SVEC
- Chemical, Molecular Beam Epitaxy Growth

### Texas A&M
- Micro Heat Pipe Evaluation
- Frozen Startup of Heat Pipe
- Microwave Power Transmission

### University of Alabama-Birmingham
- Protein Crystal Growth

### University of Alabama-Huntsville
- Polymer Foam
- Atomic Oxygen
- Electroerosion
- 3-D Accelerometer
- Implantable Polymers
- Nuclear Track Detectors
- Space Experiment Facility
- Non-Linear Optical Materials
- Sintered & Alloyed Materials
- High-Temp Superconductors
- Materials Dispersion Apparatus

### University of Maryland
- Hybrid Networks

### WCSAR
- Astroculture™
- Bioregenerative Water System

### A Major Objective:

To produce a body of knowledge and experience that will allow U.S. industrial entities to make informed decisions regarding their participation in commercial space endeavors.
COMPARISON OF COMMERCIAL OPTIONS

A Private Entity May Ask:

What options do I have to participate in a commercial space endeavor, and what are the relative comparisons of:

1. Risk to my Investment?
2. Cost of participating?
3. Retention of Intellectual Property?

<table>
<thead>
<tr>
<th></th>
<th>Join a CCDS</th>
<th>Negotiate a Joint Endeavor Agreement</th>
<th>Negotiate A Commercial Reimbursable Agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Risk</td>
<td>lower</td>
<td>lower</td>
<td>higher</td>
</tr>
<tr>
<td>2. Cost</td>
<td>lower</td>
<td></td>
<td>higher</td>
</tr>
<tr>
<td>3. Intel. Prop.</td>
<td>keep some</td>
<td></td>
<td>keep all</td>
</tr>
</tbody>
</table>
Commercial Payload Evolution to Space Station

48 Shuttle payload-flights so far

Various shuttle experiments

4/93

SPACEHAB - 2 per year

Orbit and recovery (COMmercial Experiment Transporter - COMET - 1 per year)

Suborbital rockets

~30-35 KC-135 payload-flights per year

Parabolic aircraft flights

COMET
CONESTOGA Launch Vehicle
1620 Configuration

Payload
Motors
EER provided hardware
Attach hardware/misc.

A = Castor NA
B = Castor NB
1 = 1st Stage
2 = 2nd Stage

EER Systems, Inc., Space Services Division
Figure 1.4-2 Cutaway View of COMET FreeFlyer
Payload Resources

**CONFIGURATIONS**

**All Locker Configuration**
- 71 lockers (max)

**Rack & Locker Configurations**
- 1 rack / 61 lockers (max)
- 2 racks / 51 lockers (max)

**TOTAL PAYLOAD RESOURCES**

<table>
<thead>
<tr>
<th></th>
<th>English</th>
<th>Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mass:</strong></td>
<td>3000 lb</td>
<td>1360 kg</td>
</tr>
<tr>
<td><strong>Volume:</strong></td>
<td>1100 ft³</td>
<td>31.1 m³</td>
</tr>
<tr>
<td><strong>Power:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>DC:</strong></td>
<td>1750 - 3500 W</td>
<td></td>
</tr>
<tr>
<td><strong>Asc/Des:</strong></td>
<td>300 - 625 W</td>
<td></td>
</tr>
<tr>
<td><strong>AC:</strong></td>
<td>690 VA</td>
<td></td>
</tr>
<tr>
<td><strong>Cooling:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Air:</strong></td>
<td>2000 W</td>
<td></td>
</tr>
<tr>
<td><strong>Water</strong>:</td>
<td>4000 W</td>
<td></td>
</tr>
<tr>
<td><strong>Crew:</strong></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td><strong>Other:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Command/data subsystems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Fire detection/suppression</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Vacuum venting</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*With 2 Orbiter Feeders, DC = 3150 W

**Maximum water cooling level includes 2 kW plus whatever air capability is not used. (The orbiter can provide up to 6 kW cooling total on a special case basis.)

Mission planning will assess the compatibility of payloads in order to maximize the resources provided to each.
Spacehab Racks

Double Rack
(45 cu. ft., 1209 lb Experiment)

Single Rack
(22.5 cu. ft., 855 lb Experiment)

TRANSITION OF SPACEHAB PAYLOADS TO SSF

RACK PAYLOAD ENVELOPES

<table>
<thead>
<tr>
<th>SPACEHAB</th>
<th>SSF ISPR</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Diagram" /></td>
<td><img src="image2.png" alt="Diagram" /></td>
</tr>
</tbody>
</table>

- **R** = PAYLOAD ENVELOPE
- RESIZED VALVES AND PLUMBING
### RACK COMPARISON SUMMARY

<table>
<thead>
<tr>
<th>SPACEHAB</th>
<th>SPACE STATION FREEDOM</th>
</tr>
</thead>
<tbody>
<tr>
<td>80 in. (2032 mm) High</td>
<td>78.7 in. (1999 mm) High</td>
</tr>
<tr>
<td>42.126 in. (1070 mm) Wide</td>
<td>41.5 in. (1054.1 mm) Wide</td>
</tr>
<tr>
<td>35 in. (889 mm) Deep</td>
<td>38.7 in. (993 mm) Deep</td>
</tr>
<tr>
<td>9.28 in. (235.71 mm) Base</td>
<td>No Base</td>
</tr>
<tr>
<td>57 cu. ft. (1.61 cu. m) Inside Envelope</td>
<td>55 cu. ft. (1.55 cu. m) Inside Envelope</td>
</tr>
<tr>
<td>45 cu. ft. (1.27 cu. m) Design Volume</td>
<td>40 cu. ft. (1.13 cu. m) Max Rectangular Volume</td>
</tr>
<tr>
<td>19.9 sq. ft. (1.85 sq. m) Single Bay</td>
<td>15.8 sq. ft. (1.47 sq. m) Single Bay</td>
</tr>
<tr>
<td>18.7 sq. ft. (1.74 sq. m) Double Bay</td>
<td>15.0 sq. ft. (1.39 sq. m) Double Bay</td>
</tr>
<tr>
<td>EIA-RS-310-C</td>
<td>EIA-RS-310-C</td>
</tr>
<tr>
<td>17.73 in. (450.34 mm) Single Bay</td>
<td>17.75 in. (450.85 mm) Single Bay</td>
</tr>
<tr>
<td>37.73 in. (958.34 mm) Double Bay</td>
<td>37.5 in. (952.5 mm) Double Bay</td>
</tr>
<tr>
<td>1250 lbs. (567 kg)</td>
<td>882 lbs. (400 kg) Standard</td>
</tr>
<tr>
<td></td>
<td>1554 lbs. (700 kg) Optional</td>
</tr>
</tbody>
</table>

### TRANSITION OF SPACEHAB PAYLOADS TO SSF

<table>
<thead>
<tr>
<th>SPACEHAB</th>
<th>SPACE STATION FREEDOM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rack Base, Front</td>
<td></td>
</tr>
<tr>
<td>1 kw (average) 2 kw (peak) 28 Volts DC</td>
<td>3.6, or 12 kw</td>
</tr>
<tr>
<td>690 VA, 400 Hz</td>
<td>120 Volts DC</td>
</tr>
<tr>
<td>DC POWER</td>
<td>User provides power conversion</td>
</tr>
<tr>
<td>AC POWER</td>
<td>None</td>
</tr>
<tr>
<td>2, 4, 8, 16 kbps (48 mbps optional) User provides Dedicated Experiment Processor</td>
<td>16 mbps (48 mbps total)</td>
</tr>
<tr>
<td>COMMAND AND DATA</td>
<td>1553 Data Bus Standard</td>
</tr>
<tr>
<td>1 kw average per rack 2 kw total module</td>
<td>802.4 FDDI Optional</td>
</tr>
<tr>
<td>RACK AIR COOLING</td>
<td>User purchases MDM</td>
</tr>
<tr>
<td>PAYLOAD WATER LOOP CAPACITY</td>
<td>User Provides Dedicated Experiment Processor if required</td>
</tr>
<tr>
<td>1 kw water loop capacity</td>
<td>1.2 kw max per rack</td>
</tr>
<tr>
<td>VACUUM</td>
<td>3.6 kw total module</td>
</tr>
<tr>
<td>1.4 E-5 Torr to 1.0 E-6 Torr</td>
<td>8 kw</td>
</tr>
<tr>
<td>VACUUM</td>
<td>10 E-3 Torr</td>
</tr>
</tbody>
</table>
Locker Capacity

<table>
<thead>
<tr>
<th></th>
<th>English</th>
<th>Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard Accom</td>
<td>42 lbs</td>
<td>20.9 kg</td>
</tr>
<tr>
<td>Design Limit</td>
<td>60 lbs</td>
<td>27.2 kg</td>
</tr>
<tr>
<td>C.G.:</td>
<td>14 in^1</td>
<td>35.6 cm</td>
</tr>
<tr>
<td>Volume:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entire Locker</td>
<td>2.0 ft^3</td>
<td>0.057 m^3</td>
</tr>
<tr>
<td>Small Tray</td>
<td>0.9 ft^3</td>
<td>0.025 m^3</td>
</tr>
<tr>
<td>Large Tray</td>
<td>1.9 ft^3</td>
<td>0.054 m^3</td>
</tr>
</tbody>
</table>

Data: Accommodated through manifesting of compatible payloads.

D.C. Power
On Orbit: 115 W (Continuous) 180 W (Peak) for TBD Min @ 28 +/-4 VDC

Ascent/Descent**

Cooling: Payload heat generation above 60W requires forced air cooling.

SPACEHAB had the capability of accommodating Middeck locker payloads without modification.

Flight Schedule

Flight 1  April 1993
Flight 2  October 1993
Flight 3  April 1994
Flight 4  October 1994
Flight 5  March 1995
Flight 6  August 1995

Subsequent Flights will be Scheduled to Satisfy Market Demands.
SPACEHAB Payload Processing Facility (SPPF)

- **35,000 square feet of payload integration, test, training & support facilities**
- **6,000 square feet of Customer Work Area (CWA), subdivided into industrial secure rooms**
- **Shipping / Receiving provided for receipt of hardware.**
- **Clean Room - 100K class conditions in shipping / receiving, CWAs, & integration hall**
- **General classrooms, conference rooms, copiers, and fax machine available for use on shared basis.**
- **Availability date: 3/1/91**
- **Located on commercial site near KSC.**
## FLIGHTS OF U.S. COMMERCIAL PAYLOADS

<table>
<thead>
<tr>
<th>PAYLOAD NAME</th>
<th>No. Of FLIGHTS</th>
<th>MISSION(S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTROCULTURE</td>
<td>1</td>
<td>STS 50</td>
</tr>
<tr>
<td>AUTOMATED GENERIC BIOPROCESSING APPARATUS</td>
<td>2</td>
<td>Consort 3, 4</td>
</tr>
<tr>
<td>BIOMODULE</td>
<td>2</td>
<td>Consort 3, 4</td>
</tr>
<tr>
<td>ROGUE INSTRUMENTATION MATERIALS DISPERSION APP</td>
<td>2</td>
<td>STS 37, 43</td>
</tr>
<tr>
<td>CONTINUOUS FLOW ELECTROPHORESIS (I, II, &amp; III)</td>
<td>7</td>
<td>STS 4, 6, 7, 8, 12, 16, 23</td>
</tr>
<tr>
<td>DEMIXING OF IMMISCIBLE POLYMERS MIXER</td>
<td>2</td>
<td>Consort 1, 3</td>
</tr>
<tr>
<td>DIFFUSIVE MIXING OF ORGANIC SOLUTIONS</td>
<td>2</td>
<td>STS 14, 23</td>
</tr>
<tr>
<td>DIRECTED POLYMERIZATION APPARATUS (USML-1 GBX exper.)</td>
<td>1</td>
<td>STS 50</td>
</tr>
<tr>
<td>ELASTOMER MODIFIED EPOXY RESINS HEATERS</td>
<td>2</td>
<td>Consort 1, 3</td>
</tr>
<tr>
<td>ELECTRODEPOSITION CELLS</td>
<td>4</td>
<td>Consort 1, 3, 4, STS 40 (GAS 105)</td>
</tr>
<tr>
<td>EQUIPMENT FOR CONTROLLED LIQUID PHASE SINTERING</td>
<td>1</td>
<td>Consort 4</td>
</tr>
<tr>
<td>FLUID EXPERIMENT APPARATUS</td>
<td>2</td>
<td>STS 30, 32</td>
</tr>
<tr>
<td>FOAM FORMATION DEVICE</td>
<td>2</td>
<td>Consort 1, 3</td>
</tr>
<tr>
<td>GELATION OF SOLS. APPLIED MICROGRAVITY RESEARCH</td>
<td>1</td>
<td>STS 42</td>
</tr>
<tr>
<td>GENERIC BIOPROCESSING APPARATUS</td>
<td>1</td>
<td>STS 50</td>
</tr>
<tr>
<td>PROTEIN CRYSTAL GROWTH (Hand-Held VDA, PCC, CRIM, GBX)</td>
<td>1*</td>
<td>STS 16, 19, 23, 24, 26, 29, 32, 31, 37, 43, 48, 42, 50</td>
</tr>
<tr>
<td>INVESTIGATIONS INTO POLYMER MEMBRANE PROCESSES</td>
<td>2</td>
<td>Consort 3, 4</td>
</tr>
<tr>
<td>INVESTIGATIONS INTO POLYMER MEMBRANE PROCESSING</td>
<td>7</td>
<td>STS 31, 41, 43, 48, 42, 45, 50</td>
</tr>
<tr>
<td>MATERIALS DISPERSION APPARATUS</td>
<td>3</td>
<td>Consort 1, 3, 4</td>
</tr>
<tr>
<td>METAL SINTERING FURNACE</td>
<td>1</td>
<td>Consort 1</td>
</tr>
<tr>
<td>NON-LINEAR OPTICAL CRYSTAL GROWTH (DAN) - UAH/IBM</td>
<td>1</td>
<td>STS 40 (GAS 105)</td>
</tr>
<tr>
<td>NON-LINEAR OPTICAL CRYSTAL GROWTH (INCA) - UAH/TBE</td>
<td>1</td>
<td>STS 40 (GAS 105)</td>
</tr>
<tr>
<td>PHYSICAL VAPOR TRANSPORT OF ORGANIC SOLIDS</td>
<td>2</td>
<td>STS 20, 26</td>
</tr>
<tr>
<td>PHYSIOLOGICAL SYSTEMS EXPERIMENTS</td>
<td>1</td>
<td>STS 41</td>
</tr>
<tr>
<td>PLASMA PARTICLE GENERATION</td>
<td>1</td>
<td>Consort 3</td>
</tr>
<tr>
<td>POLYMER CURING EXPERIMENT</td>
<td>1</td>
<td>Consort 4</td>
</tr>
<tr>
<td>POLYMER MORPHOLOGY</td>
<td>1</td>
<td>STS 34</td>
</tr>
<tr>
<td>POLYMER THIN FILMS</td>
<td>2</td>
<td>Consort 3, STS 40 (GAS 105)</td>
</tr>
<tr>
<td>SEPARATION OF AQUEOUS PHASES</td>
<td>1</td>
<td>STS 40 (GAS 105)</td>
</tr>
<tr>
<td>SPACE FORMED STRUCTURAL BEAM (Foam Formation Device)</td>
<td>1</td>
<td>Consort 4</td>
</tr>
<tr>
<td>YEAST EXPERIMENT</td>
<td>1</td>
<td>STS 40 (GAS 105)</td>
</tr>
<tr>
<td>ZEOLITE CRYSTAL GROWTH</td>
<td>1</td>
<td>STS 50</td>
</tr>
</tbody>
</table>

32 TOTAL PAYLOAD HARDWARE ITEMS | 73 TOTAL NUMBER OF PAYLOAD FLIGHTS**

* The Protein Crystal Growth experiments were shared between the OCP and OSSA
** A payload-flight = one flight of one payload. Therefore, one flight with 3 payloads = 3 payload-flights

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## SSF RESOURCE ALLOCATIONS

<table>
<thead>
<tr>
<th></th>
<th>NASA U.S.A.</th>
<th>MOSST Canada</th>
<th>ESA Europe</th>
<th>STA Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utilization Resources</td>
<td>71.4%</td>
<td>3%</td>
<td>12.8%</td>
<td>12.8%</td>
</tr>
</tbody>
</table>

1997 OCP SSF Resources

- Pressurized Up Mass: 4,352 kg
- Pressurized Down Mass: 3,784 kg
- Unpressurized Up Mass: 4,209 kg
- Unpressurized Down Mass: 7,073 kg
- Volume Up: 9.5 DRE
- Volume Down: 7.1 DRE
- Power: 3 kW
- Downlink: 10,472 kb/s
- Crew Time: 436 hours
- Data Storage: 92 Mbytes
- Racks Occupied On-Orbit: 5 DRE
- Truss Attach Points: 0.7 APs

* Utilization planning guidelines allow the total resources used by NASA's User Sponsors to equal 125%, for the launch minus 5 year timeframe.
The Office of Commercial Programs is Producing

- A body of applications-oriented scientific knowledge
- An experience base in payload flight hardware development and integration
- A complement of payload hardware
- Transportation systems and carriers

that will allow us to transition to Space Station Freedom
LARGE SCALE CRYSTALLIZATION OF PROTEIN PHARMACEUTICALS IN MICROGRAVITY VIA TEMPERATURE CHANGE*

Presented by Marianna M. Long, Ph.D.
Center for Macromolecular Crystallography
University of Alabama at Birmingham

ABSTRACT

The major objective of this research effort is the temperature driven growth of protein crystals in large batches in the microgravity environment of space. Pharmaceutical houses are developing protein products for patient care, for example, human insulin, human growth hormone, interferons and tissue plasminogen activator or TPA, the clot buster for heart attack victims. Except for insulin, these are very high value products; they are extremely potent in small quantities and have a great value per gram of material. It is feasible that microgravity crystallization can be a cost recoverable, economically sound final processing step in their manufacture.

Large scale protein crystal growth in microgravity has significant advantages from the basic science and the applied science standpoints. Crystal growth can proceed unhindered due to lack of surface effects. Dynamic control is possible and relatively easy. The method has the potential to yield large quantities of pure crystalline product. Crystallization is a time honored procedure for purifying organic materials and microgravity crystallization could be the final step to remove trace impurities from high value protein pharmaceuticals. In addition, microgravity grown crystals could be the final formulation for those medicines that need to be administered in a timed release fashion. Long lasting insulin, insulin lente, is such a product. Also crystalline protein pharmaceuticals are more stable for long-term storage. Temperature, as the initiation step, has certain advantages. Again, dynamic control of the crystallization process is possible and easy. A temperature step is non-invasive and is the most subtle way to control protein solubility and therefore crystallization. Seeding is not necessary. Changes in protein and precipitant concentrations and pH are not necessary. Finally, this method represents a new way to crystallize proteins in space that takes advantage of the unique microgravity environment.

The hardware design for the Protein Crystallization Facility (PCF) entails four polysulfone cylinders (500, 200, 100, 50 ml total volume) of different heights and same diameters. The aluminum cap of each cylinder is apposed to the heating element of the R/IM and the temperature is decreased from 40°C to 22°C early in the mission for insulin, the sample used for STS-37 and STS-3. The four cylinder sizes resulted in four different temperature gradients. On STS-37, the temperature was ramped down in four steps over 23 hours, while on STS-43 the ramp was in one step.

The results from these two flights showed that the hardware performed perfectly, many crystals were produced and they were much larger than their ground grown controls. Morphometric analysis was done on over 4,000 crystals to establish crystal size, size distribution and relative size. Space grown crystals were remarkably larger than their earth grown counterparts and crystal size was a function of PCF volume. For example, for the largest volume PCF (500 ml) from STS-37, the space crystals were 10 times bigger than controls while for the smallest volume (50 ml) they were 2 times bigger. That size distribution for the space grown crystals was a function of PCF volume may indicate that ultimate size was a function of temperature gradient. Since the insulin protein concentration was very low, 0.4 mg/ml, the size distribution could also be following the total amount of protein in each of the PCFs. X-ray analysis showed that the bigger space grown insulin crystals diffracted to higher resolution than their ground grown controls. When the data were normalized for size, they still indicated that the space crystals were better than the ground crystals.

*Funded by NASA grant NAGW-813 to Charles E. Bugg
CENTER FOR
MACROMOLECULAR CRYSTALLOGRAPHY

A NASA CENTER FOR THE COMMERCIAL DEVELOPMENT
OF SPACE

PROTEIN CRYSTALLIZATION
FACILITY
(PCF)

Presentation by Marianna M. Long
Space Station Freedom
Utilization Workshop
Huntsville, Alabama
August 4-6, 1992

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PROTEIN CRYSTALLIZATION FACILITY
(PCF)

OBJECTIVES

• To grow protein crystals in large batches

• To use temperature as the means to initiate and control protein crystal growth

PROTEIN CRYSTALLIZATION FACILITY
(PCF)

ADVANTAGES OF LARGE SCALE PROTEIN CRYSTAL GROWTH

• No surface effects to interfere with crystal growth

• Easy dynamic control is possible

• Yields large quantities of large, very pure crystals
  • Purity of protein is achieved
  • Uniformity of size of protein crystal is possible
  • Patentability is enhanced and this stimulates commercial interest
PROTEIN CRYSTALLIZATION FACILITY (PCF)

ADVANTAGES OF TEMPERATURE IN PROTEIN CRYSTAL GROWTH

- Dynamic control is possible
- Non-invasive, most subtle way to control protein solubility
- No seeding is necessary
- No changes in [protein], [precipitant], or pH are necessary
- Represents a new way to crystallize proteins that takes advantage of microgravity environment

PROTEIN CRYSTALLIZATION FACILITY (PCF)

HARDWARE DESIGN

- Polysulfone with neoprene O-rings
- 4 cylinders: 500ml, 200ml, 100ml, 50ml
- All have the same diameter with different heights
- The metal cap of each cylinder is apposed to the heating element of the R/IM and the temperature is decreased from 40C to 22C early in flight
- Insulation is around each cylinder
- The 4 sizes will result in 4 different temperature gradients
PROTEIN CRYSTALLIZATION FACILITY (PCF)

TEMPERATURE STEPS

STS-37

<table>
<thead>
<tr>
<th>TIME</th>
<th>TEMP STEP</th>
</tr>
</thead>
<tbody>
<tr>
<td>L+3</td>
<td>40-&gt;36C</td>
</tr>
<tr>
<td>L+9</td>
<td>36-&gt;32C</td>
</tr>
<tr>
<td>L+19</td>
<td>32-&gt;28C</td>
</tr>
<tr>
<td>L+26</td>
<td>28-&gt;22C</td>
</tr>
</tbody>
</table>
Length and Width of "Rosette" Crystals

- Flight Length
- Ground Length
- Flight Width
- Ground Width

All n=150 except flight 50 (n=100)

PCF volume (ml)

STS-37

537
Comparison of Flight to Ground "Rosette" Crystals

by: \[ \frac{\text{flight crystals}}{\text{ground crystals}} \]

<table>
<thead>
<tr>
<th>PCF</th>
<th>Length</th>
<th>Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>5.94</td>
<td>4.13</td>
</tr>
<tr>
<td>200</td>
<td>4.71</td>
<td>3.43</td>
</tr>
<tr>
<td>100</td>
<td>2.40</td>
<td>1.74</td>
</tr>
<tr>
<td>50</td>
<td>2.76</td>
<td>2.34</td>
</tr>
</tbody>
</table>

STS-37
Comparison of Flight to Ground "Rosette" Crystals

STS-37
"Rosette" Crystal Size on Side of 500ml PCF Relative to Location Down Long Axis

STS-37

Flight Length
Ground Length
Flight Width
Ground Width
Length and Width of Single Crystals

![Graph showing the comparison between flight and ground lengths of single crystals as a function of PCF volume (ml). The graph includes data points for different PCF volumes and indicates the number of observations (n) for each point. The graph is labeled with 'n=100', 'n=80', 'n=300', 'n=150', and 'n=100'.]
Comparison of Flight to Ground Single Crystals

by: \( \frac{\text{flight crystals}}{\text{ground crystals}} \)

<table>
<thead>
<tr>
<th>PCF</th>
<th>Length</th>
<th>Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>10.26</td>
<td>3.96</td>
</tr>
<tr>
<td>200</td>
<td>8.66</td>
<td>3.66</td>
</tr>
<tr>
<td>100</td>
<td>2.42</td>
<td>1.84</td>
</tr>
<tr>
<td>50</td>
<td>2.42</td>
<td>2.24</td>
</tr>
</tbody>
</table>

STS-37
Comparison of Flight to Ground Single Crystals

STS-37
Single Crystal Size on Side of 500ml PCF Relative to Location Down Long Axis

STS-37

- Flight Length
- Ground Length
- Flight Width
- Ground Width

544
PROTEIN CRYSTALLIZATION FACILITY
   (PCF)
TEMPERATURE STEPS
   STS-43

<table>
<thead>
<tr>
<th>TIME</th>
<th>TEMP STEP</th>
</tr>
</thead>
<tbody>
<tr>
<td>L+4</td>
<td>40→22C</td>
</tr>
</tbody>
</table>
Comparison of Flight to Ground Single Crystals

by: \( \frac{\text{flight crystals}}{\text{ground crystals}} \)

<table>
<thead>
<tr>
<th>PCF</th>
<th>Length</th>
<th>Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>4.58</td>
<td>2.55</td>
</tr>
<tr>
<td>200</td>
<td>4.65</td>
<td>2.64</td>
</tr>
<tr>
<td>100</td>
<td>4.12</td>
<td>2.68</td>
</tr>
<tr>
<td>50</td>
<td>2.76</td>
<td>1.65</td>
</tr>
</tbody>
</table>
Comparison of Flight to Ground Single Crystals

STS-43
Single Crystal Size on Side of 500ml PCF Relative to Location Down Long Axis

STS-43

- Flight Length
- Ground Length
- Flight Width
- Ground Width

Flight Length
Ground Length
Flight Width
Ground Width

millimeters

0.5
0.4
0.3
0.2
0.1
0

top mid bot top mid bot top mid bot top mid bot top mid bot top mid bot
<I> in bin (peaks>5sigma, sigma units)

Ground Based
Space Crystals
Giants of Space

Resolution

12.00 7.12 5.07 3.93 3.21 2.71 2.35
log\langle I\rangle in bin (peaks>5\sigma, raw units)

Ground Based
Space Crystals
Giants of Space
PROTEIN CRYSTALLIZATION FACILITY

(PCF)

PROTEIN TO BE CRYSTALLIZED

- Insulin, at 0.4 mg/ml, in phosphate buffer, will be the first protein to fly in the PCF

- The temperature is decreased from 40°C to 22°C early in the flight
COMMERCIAL OPPORTUNITIES IN BIOSEPARATIONS AND PHYSIOLOGICAL TESTING ABOARD SPACE STATION FREEDOM

Presented by Dr. W. C. Hymer
Center for Cell Research
A NASA Center for the Commercial Development of Space
The Pennsylvania State University

ABSTRACT

The Center for Cell Research (CCR) is a NASA Center for the Commercial Development of Space which has as its main goal encouraging industry-driven biomedical/biotechnology space projects. Space Station Freedom (SSF) will provide long duration, crew-tended microgravity environments which will enhance the opportunities for commercial biomedical/biotechnology projects in bioseparations and physiological testing.

The CCR bioseparations program, known as USCEPS (for United States Commercial Electrophoresis Program in Space), is developing access for American industry to continuous-flow electrophoresis aboard SSF. In space, considerable scale-up of continuous free-flow electrophoresis is possible for cells, subcellular particles, proteins, growth factors and other biological products. The lack of sedimentation and buoyancy-driven convection flow enhances purity of separations and the amount of material processed/time.

Through the CCR's physiological testing program, commercial organizations will have access aboard SSF to physiological systems experiments (PSEs); the Penn State Biomodule; and telemicroscopy. Physiological systems experiments involve the use of live animals for pharmaceutical product testing and discovery research. The Penn State Biomodule is a computer-controlled minilab useful for projects involving live cells or tissues and macromolecular assembly studies, including protein crystallization. Telemicroscopy will enable staff on Earth to manipulate and monitor microscopic specimens on SSF for product development and discovery research or for medical diagnosis of astronaut health problems.

Space-based product processing, testing, development and discovery research using USCEPS and CCR's physiological testing program offer new routes to improved health on Earth. Direct crew involvement in biomedical/biotechnology projects aboard SSF will enable better experimental outcomes. The current data base shows that there is reason for considerable optimism regarding what the CCDS program and the biomedical/biotechnology industry can expect to gain from a permanent manned presence in space.
"...TO SEEK AND ENCOURAGE, TO THE MAXIMUM EXTENT POSSIBLE, THE FULLEST COMMERCIAL USE OF SPACE."
CCR COMMERCIAL PARTNER PROGRAM
FOR
PRODUCT TESTING AND INDUSTRY-DRIVEN DISCOVERY RESEARCH

1. FLIGHT ACCESS
2. EXPERIMENT PLANNING AND POST FLIGHT ANALYSIS
3. PAYLOAD PLANNING, INTEGRATION, MISSION MANAGEMENT
4. FLIGHT CERTIFIED HARDWARE
5. INTELLECTUAL PROPERTY AGREEMENTS
6. SUPPORT

MAIN GOAL: ASSIST INDUSTRY IN PLANNING AND ACCOMPLISHING
BIOTECHNOLOGY/BIOMEDICAL SPACE PROJECTS

BIOSEPARATION
PHYSIOLOGICAL TESTING
ILLUMINATION
SPACE BIOTECHNOLOGY: OPPORTUNITIES FOR INVESTIGATIONS IN CELLULAR PHYSIOLOGY AND BIOSEPARATIONS
WHY SPACE BIOTECHNOLOGY

PHYSIOLOGICAL TESTING

EXPOSING ANIMALS AND MAN TO SURPRISINGLY SHORT PERIODS OF MICROGRAVITY CAUSES PHYSIOLOGICAL CHANGES WHICH RESEMBLE HUMAN DISEASES, SUCH AS OSTEOPOROSIS, MUSCLE WASTAGE, ABNORMAL HORMONE SECRETION, LOWERED IMMUNE FUNCTION AND AGING. SPACEFLOWN ANIMALS AND CELLS CAN BE USED AS MODELS FOR THESE CONDITIONS.

OBSERVED MICROGRAVITY EFFECTS

<table>
<thead>
<tr>
<th>SOUNding ROCKETS</th>
<th>U.S. SPACE SHUTTLE/ RUSSIAN SATELLITE</th>
<th>SKYLAB-MIR</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 MINUTES $\mu G$</td>
<td>7-14 DAYS $\mu G$</td>
<td>3-12 MONTHS $\mu G$</td>
</tr>
<tr>
<td>CELL PHYSIOLOGY</td>
<td>ANIMAL PHYSIOLOGY</td>
<td>EFFECTS IN HUMANS</td>
</tr>
<tr>
<td>Hybridoma production $\uparrow$</td>
<td>Bone demineralization</td>
<td>Spinal decompression</td>
</tr>
<tr>
<td>Oncogene expression $\downarrow$</td>
<td>Muscle atrophy</td>
<td>Edema</td>
</tr>
<tr>
<td>PKC pathway</td>
<td>Immune dysfunction</td>
<td>Negative calcium balance</td>
</tr>
<tr>
<td>Microtubule dysfunction</td>
<td>Endocrine dysfunction</td>
<td>Muscle weakness</td>
</tr>
<tr>
<td>Electrophoretic cell separation $\uparrow$</td>
<td>Low hematocrit</td>
<td>Cardiovascular changes</td>
</tr>
<tr>
<td></td>
<td>Loss of body fluids</td>
<td>Neurovestibular changes</td>
</tr>
<tr>
<td></td>
<td>Altered liver enzymes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wound healing $\downarrow$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bone breaking $\downarrow$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
OBSERVED MICROGRAVITY EFFECTS

Oncogene Expression
- Autoradiography of ^3H-labeled DNA bands

Bone Mineralization
- total body calcium (percentage of body mass)

Bone Strength
- quadriceps, cancellous bending in 200N - m

SL-3 (GH)

COSMOS 2044 (GH)

COSMOS 1887 (GH)

COSMOS 2044 (GH) (TS)
SINGLE CELLS IN REDUCED GRAVITY

- BACTERIAL PROLIFERATE MORE RAPIDLY
- BACTERIAL CONJUNCTION RATE INCREASED
- INCREASED RESISTANCE OF E. COLI TO ANTIBIOTICS
- REDUCTION IN SPORULATION RATE
- 4 FOLD INCREASE IN PROLIFERATION OF PARAMECIUM TETRAURELIA
- VIRTUAL TOTAL SUPPRESSION OF BLASTOGENIC RESPONSE IN T-LYMPHOCYTES EXPOSED TO CON-A
- RAT PITUITARY CELLS SHOW 20 FOLD SUPPRESSION OF BASAL GH RELEASE POSTFLIGHT
- 5 FOLD INCREASE IN GAMMA-INTERFERON PRODUCTION IN $\mu$G
- INCREASE IN MEMBRANE FUSION EVENTS (HYBRIDOMA)
- DECREASED GLUCOSE CONSUMPTION IN HUMAN EMBRYONIC LUNG FIBROBLASTS

FIRST COMMERCIAL PHYSIOLOGICAL TESTING

EXPERIMENT IN SPACE

- GENENTECH, INC. AND CENTER FOR CELL RESEARCH
- SPACE SHUTTLE DISCOVERY OCTOBER 6, 1990
- COMMERCIAL GOAL: PROPRIETARY
- EXPERIMENT MEASURED THE EFFECT OF A NUMBER OF PROTEINS
- GENENTECH'S ASSESSMENT: "THE SYSTEM CAN WORK WITH PRIVATE ENTERPRISE"
CENTER FOR CELL RESEARCH

HARDWARE
CONSORT SOUNDING ROCKET MISSIONS DEMONSTRATE VERSATILITY OF BIOMODULE

ABOARD CONSORT 4, THE PENN STATE BIOMODULE WAS USED SUCCESSFULLY FOR THE FIRST TIME TO STUDY MICROGRAVITY EFFECTS ON MAMMALIAN CELLS, PLANT TISSUES AND PROTEIN CRYSTALS EXTENDING ITS UTILITY TO THREE MORE CLASSES OF BIOLOGICAL MATERIALS OF COMMERCIAL INTEREST.
TELEMICROSCOPY

THE CORABI/CCR TELEMICROSCOPY PROJECT WILL PROVIDE THE COMMERCIAL BIOMEDICAL/BIOTECHNOLOGY COMMUNITY WITH THE OPPORTUNITY TO STUDY MICROSCOPIC SPECIMENS ABOARD SPACE STATION FREEDOM FROM THE GROUND.

APPLICATIONS: MONITOR PRODUCT PROCESSING, PRODUCTION, TESTING COMMERCIAL DISCOVERY RESEARCH

ASTRONAUT HEALTH
CONCLUSION

SPACE-BASED PRODUCT PROCESSING, TESTING, DEVELOPMENT AND DISCOVERY RESEARCH USING USCEPS AND CCR’S PHYSIOLOGICAL TESTING PROGRAM OFFER NEW ROUTES TO IMPROVED HEALTH ON EARTH.

THE CCR AND SSF WILL HELP AMERICAN INDUSTRY TO TAKE THOSE ROUTES AND TO USE MICROGRAVITY AS AN ENABLING FORCE TO ACHIEVE PRODUCT-ORIENTED GOALS.
CONSORTIUM FOR MATERIALS DEVELOPMENT IN SPACE
INTERACTION WITH SPACE STATION FREEDOM

Presented by Charles A. Lundquist and Valerie Seaquist
Consortium for Materials Development in Space
The University of Alabama in Huntsville

ABSTRACT

The Consortium for Materials Development in Space (CMDS) is one of seventeen Centers for the Commercial Development of Space (CCDS) sponsored by the Office of Commercial Programs of NASA. The CMDS formed at the University of Alabama in Huntsville in the fall of 1985. The Consortium activities therefore will have progressed for over a decade by the time Space Station Freedom (SSF) begins operation. The topic to be addressed here is: What are the natural, mutually productive relationships between the CMDS and SSF? For management and planning purposes, the Consortium organizes its activities into a number of individual projects. Normally, each project has a team of personnel from industry, university and often government organizations. This is true for both product-oriented materials projects and for infrastructure projects. For various of these projects Space Station offers specific mutually productive relationships. First, SSF can provide a site for commercial operations that have evolved as a natural stage in the life cycle of individual projects. Efficiency and associated cost control lead to another important option. With SSF in place, there is the possibility to leave major parts of processing equipment in SSF, and only bring materials to SSF to be processed and return to earth the treated materials. This saves the transportation costs of repeatedly carrying heavy equipment to orbit and back to the ground. Another generic feature of commercial viability can be the general need to accomplish large through-put or large scale operations. The size of SSF lends itself to such needs. Also in addition to processing equipment, some of the other infrastructure capabilities developed in CCDS projects may be applied on SSF to support product activities. The larger SSF program may derive mutual benefits from these infrastructure abilities.
Consortium for Materials Development in Space Interaction with Space Station Freedom

1. Background

The Consortium for Materials Development in Space (CMDS) is one of seventeen Centers for the Commercial Development of Space (CCDS) sponsored by the Office of Commercial Programs of NASA. In addition to NASA, the Consortium receives support from affiliated industries and from the State of Alabama. The CMDS formed at the University of Alabama in Huntsville in the fall of 1985.

The Consortium activities therefore will have progressed for over a decade by the time Space Station Freedom (SSF) begins operation. The topic to be addressed here is: What are the natural, mutually productive relationships between the CMDS and SSF? To answer that question, a basic understanding of the CMDS activities is needed; Section 2 sketches those activities. Section 3 then shows how natural interactions arise between CMDS and SSF.

2. Current Activities of the Consortium

When it formed, the Consortium adopted three fundamental concepts to characterize its scope. These were:

- Commercial materials development that benefit from unique attributes of space
- Commercial applications of physical chemistry and materials transport
- Prompt and frequent experiments and operations in orbit

As intended here, "materials" is a broad term including inorganic, organic and living materials. These concepts have continued to be applicable to this day.

However, during its first years of operation, the Consortium recognized that it needed also to address infrastructure issues such as:

- Processing equipment for space use
- Rocket vehicles for access to space
- Environment measurements in spacecraft

The CMDS added such topics to its activities, as did other Centers for Commercial Development in Space.

For management and planning purposes, the Consortium organizes its activities into a number of individual projects. Every project must have an appropriate space involvement. Normally, each project has a team of personnel from industry, university and often government organizations. This is true for both product-oriented materials projects and for infrastructure projects.

The materials projects, particularly, are expected to go through a life cycle beginning with exploratory tests of a concept, continuing through development operations, and finally reaching a state of maturity and independence. As individual projects reach a mature, independent status, they can be replaced by new projects starting with a concept to be explored. At each step in a project's life cycle, the project is evaluated for viability and is continued or terminated. The commercial prospects for the project and industrial interest are key factors in the evaluation process.
Equipment for use in space is an essential feature of each project. The Consortium has adopted an evolutionary equipment concept, in which equipment will evolve through several modest, periodic steps from a simple initial form. This approach assures at any time that the subsequent operations are the next logical step to be performed based on experience to date. It also enhances the probabilities of success because each step incorporates the positive features of its predecessors. Specifically, the equipment candidates for flight on SSF would be picked from the evolutionary flow at the time they are needed for flight.

The present Consortium projects and infrastructure services are listed in Table 1. The potential interactions with SSF can be examined on a project by project basis.

3. CMDS Relationship with SSF

Given the characteristics of the CMDS operations as sketched in Section 2, it is now possible to look for the natural mutually productive relationships between CMDS and SSF. The first option follows immediately from the last thoughts in Section 2; SSF can provide a site for commercial operations that have evolved as a natural stage in the life cycle of individual projects. Indeed, the examples offered below have this feature.

Efficiency and associated cost control lead to another important option. With SSF in place, there is the possibility to leave major parts of processing equipment in SSF, and only bring materials to SSF to be processed and return to earth the treated materials. This saves the transportation costs of repeatedly carrying heavy equipment to orbit and back to the ground.

Another generic feature of commercial viability can be the general need to accomplish large through-put or large scale operations. The size of SSF lends itself to such needs.

Also in addition to processing equipment, some of the other infrastructure capabilities developed in CCDS projects may be applied on SSF to support product activities. The larger SSF program may derive mutual benefits from these infrastructure abilities.

To illustrate these general relationships, specific examples can be drawn from the list of projects in Table 1. As a first example, the Organic Separation or the Materials Dispersion and Biodynamics Projects can illustrate the role of SSF as a site for commercial operations. Both of these projects envision eventual service operations on a carrier such as SSF. In such an operation, a service company provides a complement of basic equipment which is left in orbit and upgraded in a modular way from time-to-time. The company provides services to many customers using the equipment on SSF. The human involvement with such equipment and operations offered by SSF is valuable, particularly with living cells which need careful handling. The next speaker in this session will have much more to say about the promise of biodynamics activities on SSF.

A related subject is the infrastructure problem of keeping living cells in a satisfactory environment from the time they are delivered for loading on the Shuttle for transportation to SSF until they are unloaded from the Shuttle upon return to earth. This infrastructure problem is being solved for the Organic Separation Project during its planned flights on Spacehab. Spacehab provides power for environment control to the Organic Separation equipment from delivery, through launch, orbital operations, return to earth and until unloading at the landing site. The same continuous service is needed for living cells on their way to and from SSF. One attractive solution is to used Spacehab as a logistic carrier to and from SSF, in which case the commercial Spacehab infrastructure provision for living cells also becomes the SSF solution. This option is illustrated in further detail in the Spacehab exhibit at this Conference.
# TABLE 1

## CMDS COMMERCIAL POTENTIAL

<table>
<thead>
<tr>
<th>PROJECT</th>
<th>INDUSTRY PARTNER</th>
<th>POTENTIAL PRODUCTS/SERVICES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrodeposition</td>
<td>McDonnell Douglas Space Sys. Co.</td>
<td>Improved surface coatings</td>
</tr>
<tr>
<td>Physical vapor transport crystal growth</td>
<td>Boeing Aerospace</td>
<td>ZnSe electrooptical devices</td>
</tr>
<tr>
<td>Non-linear optical organic materials</td>
<td>Teledyne Brown Engineering</td>
<td>Electrooptical Devices</td>
</tr>
<tr>
<td>Materials preparation and longevity in hypothermal oxygen</td>
<td>Physical Sciences, Inc., AZ Technology</td>
<td>Spacecraft surface coatings Atomic oxygen measurement devices</td>
</tr>
<tr>
<td>Sintered and alloyed materials</td>
<td>Kennametal, Inc.</td>
<td>Composites and alloys of metals and refractory materials</td>
</tr>
<tr>
<td>High-temperature superconductors</td>
<td>Lockheed, GE, LANL (AI)</td>
<td>Improved superconducting materials</td>
</tr>
<tr>
<td>Materials dispersion and biodynamics</td>
<td>Instrumentation Technology Associates, Inc.</td>
<td>Materials dispersion and biodynamic services</td>
</tr>
<tr>
<td>Organic Separation by phase partitioning of immiscible polymers</td>
<td>Interfacial Dynamics, Corp. Space Hardware Optimization Technology, Inc.</td>
<td>Cell/heavy molecule separation service Partitioning apparatus Lightweight space structures</td>
</tr>
<tr>
<td>Polymer foam formation</td>
<td>Thiolokol Corporation</td>
<td>Lightweight space structures</td>
</tr>
</tbody>
</table>

## CMDS INFRASTRUCTURE SERVICES

<table>
<thead>
<tr>
<th>INFRASTRUCTURE AREA</th>
<th>INDUSTRY PARTNER</th>
<th>SERVICE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space Experiment Furnace (SEF)</td>
<td>Boeing Commercial Space Development Company</td>
<td>In-space furnace service for multiple customers</td>
</tr>
<tr>
<td></td>
<td>McDonnell Douglas - Spacehab</td>
<td></td>
</tr>
<tr>
<td>Equipment for Controlled Liquid Phase Sintering Experiment (ECLiPSE)/Universal Small Experiment Container (USEC)</td>
<td>Wyle Laboratories</td>
<td>In-space furnace service for multiple customers</td>
</tr>
<tr>
<td>Suborbital Launch Vehicles/Services</td>
<td>EER Systems, Inc.</td>
<td>Access to 7-14 minutes microgravity for multiple customers</td>
</tr>
<tr>
<td></td>
<td>Orbital Sciences Corporation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teledyne Brown Engineering</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wyle Laboratories</td>
<td></td>
</tr>
<tr>
<td>Accelerometers</td>
<td></td>
<td>Acceleration environment measurements to support investigations</td>
</tr>
<tr>
<td>Commercial Materials Dispersion/ITA Experiment (CMIX)</td>
<td>Instrumentation Technology Associates, Inc.</td>
<td>In-space biodynamic services for multiple customers</td>
</tr>
</tbody>
</table>
The Sintered and Alloyed Materials Project (Table 1) provides a further example of the efficiency of leaving equipment in orbit. Furnaces for processing sintered and alloyed materials by their very nature tend to be large or heavy, so it is inefficient to transport them to and from orbit repeatedly. Two furnace systems are candidates for use by this project on SSF: the Space Experiment Facility (SEF) and the Equipment for Controlled Liquid Phase Sintering Experiment (ECLiPSE). Another speaker in this conference will describe SEF, so it is unnecessary to discuss it further here. The ECLiPSE is housed for safety considerations in a Universal Space Experiment Container (USEC) developed by Wyle Laboratories. USEC is explicitly designed to be compatible with Spacehab, SSF and other carriers.

The Polymer Foam Project (Table 1) is an example of a project that eventually will require a large scale operation that could be done outside SSF. An ultimate objective of the project is commercial production of large foamed structures for use in space. A demonstration of production of such a structure is appropriate for SSF sometime late in the 1990's.

Other CMDS developed capabilities of potential infrastructure interests to SSF include accelerometer systems and atomic oxygen flux measurements. An evolving accelerometer system began as a means to measure the low acceleration environment on suborbital rockets managed by the CMDS. It has developed further into a system that will be used on Spacehab and in other Shuttle circumstances. It could find use on SSF to perform similar support services for CMDS and other CCDS investigations.

One objective of the Atomic Oxygen Project is a commercially available instrument to measure the changing atomic oxygen flux that impacts the ram-facing surface of a low satellite. Such an instrument(s) could be mounted on SSF to demonstrate its long term operation and the associated data reduction capabilities.

4. Conclusion

The projects of the Consortium for Materials Development in Space are ongoing activities that employ several means to attain access to space. For some of them, operations on Space Station Freedom offer an attractive option to meet project objectives. Further, some of the infrastructure capabilities developed for the Consortium may find applications on Freedom.

References


5. CMDS Exhibit, NASA booth, Space Station Freedom Utilization Conference Exhibit.


7. Spacehab exhibit, Space Station Freedom Utilization Conference Exhibit.

The Materials Dispersion and Biodynamics Project (MDBP) focuses on dispersion and mixing of various biological materials and the dynamics of cell-to-cell communication and intracellular molecular trafficking in microgravity. Research activities encompass biomedical applications, basic cell biology, biotechnology (products from cells), protein crystal development, ecological life support systems (involving algae and bacteria), drug delivery (microencapsulation), biofilm deposition by living organisms and hardware development to support living cells on Space Station Freedom (SSF).

Project goals are to expand the existing microgravity science database through experiments on sounding rockets, the Shuttle and COMET program orbiters and to evolve, through current database acquisition and feasibility testing, to more mature and larger-scale commercial operations on SSF. Maximization of utilization of SSF for these science applications will mean that service companies will have a role in providing equipment for use by a number of different customers. An example of a potential forerunner of such a service for SSF is the Materials Dispersion Apparatus (MDA) "minilab" of Instrumentation Technology Associates, Inc. (ITA) in use on the Shuttle for the Commercial MDA-ITA Experiments (CMIX) Project. The MDA wells provide the capability for a number of investigators to perform mixing and bioprocessing experiments in space. In the area of human adaptation to microgravity, a significant database has been obtained over the past three decades. Some low-G effects are similar to Earth-based disorders (anemia, osteoporosis, neuromuscular diseases and immune system disorders). Spending in the area of Earth-based biopharmaceuticals is increasing and is projected to be in the range of $60 billion by the end of this decade, 50 times greater than it is now (Burill, G.S. and Lee, K.B. 1991. Biotech 91: A Changing Environment, Ernst and Young, San Francisco, CA). As new information targets potential profit-making processes, services and products from microgravity, commercial space ventures are expected to expand accordingly. Cooperative CCDS research in the above-mentioned areas is essential for maturing SSF biotechnology and to ensure U.S. leadership in space technology.

Currently, the MDBP conducts collaborative research with investigators at the Rockefeller University, National Cancer Institute, and the Universities of California, Arizona and Alabama in Birmingham. The growing database from these collaborations provides fundamental information applicable to development of cell products, manipulation of immune cell response, bone cell growth and mineralization and other processes altered by low-gravity. Contacts with biotechnology and biopharmaceutical companies are being increased to reach uninformed potential SSF users, provide access through the CMDS to interested users for feasibility studies and to continue active involvement of current participants. We encourage and actively seek participation of private sector companies, and university and government researchers interested in biopharmaceuticals, hardware development and fundamental research in microgravity. The project has two industry participants at present. These are Instrumentation Technology Associates, Inc. (ITA), Exton PA (hardware provider) and RANTEK, a biomedical R & D company with headquarters in Florida and offices in Huntsville.
The challenge of new ventures such as SSF, man's presence on the Moon, Mars and beyond, can be met enthusiastically with the philosophy stated by Werher von Buaun: “The value of discovery becomes clear only in the wake of the discovery itself. No one can imagine what may accrue to mankind from the space program any more than Isabella could imagine what would come of Columbus’ voyages.” The development of bio-processes and biopharmaceuticals in space leading to enhanced quality of life on Earth, ameliorating undesirable space effects and contributing to US leadership in the world economy is a reasonable expectation.
MATERIALS DISPERSION AND BIODYNAMICS

PROJECT FOCUS

- Materials dispersion and mixing in microgravity
  - Fluids and particles
  - Liquid/liquid

- Dynamics of biological systems
  - Cell-to-cell communication
  - Intracellular molecular trafficking
ACTIVITIES

ACTIVITIES ENCOMPASS SEVERAL BROAD DISCIPLINES.

- Biomedical
- Basic cell biology
- Biotechnology (products from cells)
- Protein crystal development
- Life support (algae and bacteria)
- Drug delivery (microencapsulation)
- Hardware development for cellular life support

PROJECT OBJECTIVES

To create private sector awareness of R & D potential in the space environment.

To facilitate private sector company growth in the areas of:

Services: hardware for low-g research

Products: (cells, cell products, crystals)

Processes: (ways to achieve products from low-g research)
CMIX Acronym Definition

COMMERCIAL

MDA

ITA

EXPERIMENTS

THE COMMERCIAL MDA ITA EXPERIMENTS (CMIX) PROGRAM

OVERVIEW

0 Created by - Agreement between NASA, Office of Commercial Programs and UAH.

0 Purpose - To provide additional research opportunities on the Space Shuttle for NASA's 17 CCDS.

0 Program managed by the UAH CMDS

0 Duration of Agreement - 5-year period or until 5 flights are accomplished.

0 First flight scheduled for September 1992
MDA HARDWARE

DESCRIPTION

MDA CONFIGURATION COMPARISON

Standard MDA

"Battleship" MDA
THE MDA MINILAB HARDWARE

MDA BLOCK CONFIGURATIONS
FOR FLUIDS MIXING
(Type 3 wells)

1. Launch Position
   - Bottom block

2. Microgravity Position
   - Bottom block

3. Re-entry Position
   - Bottom block

PRINCIPLE OF OPERATION

- Two blocks of inert material
- Compatible number of wells in upper and lower half
- Held together in lightweight aluminum housing
- Wells are misaligned prior to launch (materials are separate)
- In microgravity, blocks aligned allowing materials to contact
- In type 3 wells, blocks move again prior to re-entry
REAL TIME VIDEO OF MPS SAMPLE

CONTROL PANEL FOR MDA AND LMA UNITS

TYPICAL 6 MDA UNITS IN TEMPERATURE CONTROLLED C-RIM
SPACE STATION FREEDOM GREATLY INCREASES EXPERIMENT ACCOMMODATION CAPABILITY

ACCOMMODATION CAPABILITY
(Product of:
* power
* mass
* time in orbit)

UNITY

SPACELAB ON SHUTTLE

SSF MAN-TENDED CAPABILITY

17 TIMES SPACELAB CAPABILITY

SSF PERMANENTLY MANNED CAPABILITY

190 TIMES SPACELAB CAPABILITY

PROJECT GOALS

0 To expand the knowledge gained in the past three decades of microgravity research.

- Historic - effects of low-gravity on human physiology
- Recent and ongoing - low-gravity effects on single cells

0 To apply this information to develop SSF experiments and utilization in the areas of:

- Commercialization
- Basic science
EFFECTS OF LOW-GRAVITY ON HUMAN PHYSIOLOGY

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<th><strong>CORRESPONDING EARTH-BASED DISORDER</strong></th>
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<td>Bone demineralization</td>
<td>Osteoporosis due to aging</td>
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<tr>
<td>Immune response blunted</td>
<td>Immune deficiency, leukemias</td>
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<tr>
<td>Cardiac deconditioning</td>
<td>Hypertension, heart failure</td>
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<tr>
<td>Muscle deconditioning</td>
<td>Muscle wasting diseases</td>
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<tr>
<td>Decreased red blood cell count</td>
<td>Anemia</td>
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To ensure safety and maximize productivity of humans in space, continuous research is needed in the following areas:

- Cellular differentiation (i.e. stem cells to RBC's)
- Interactions of cells with drugs and medications in microgravity
- Remediation of bone mineral loss and reduced bone cell growth
- Mechanisms of reduced immune cell response and selective immunotherapy
- Mechanisms of virus infectivity in microgravity (cell receptors/cell mediated immunity)
- Nerve cell responses to stimuli (intracellular mechanisms)
MICROGRAVITY EFFECTS AT THE CELLULAR LEVEL

PROCESS ALTERED
Gene expression
Cellular metabolism
Secretory processes
T-lymphocytes
Plant cell metabolism

EFFECT OF SPACEFLIGHT
Suppression of some types
Glucose use rate lowered
Decreased or increased - cell type
Reactivity suppressed
Fatty acid content shifts
MEDICAL/BIOLOGICAL UTILIZATION OF SSF

SSF long-term, continuous lwo-g environment can provide research capability to determine

- Cellular mechanisms
- Develop remedies

Resulting in

- Spinning off new technologies
- Development of new biopharmaceuticals
- Advanced knowledge of fundamental biological processes.
# Potential Areas of Medical Commercial Application

## Potential Markets

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<td>Biodeposition (mammalian cells)</td>
<td>Liposome and drug delivery technology</td>
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<tr>
<td>Pharmaceutical</td>
<td>Protein crystals, drug design</td>
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## Benefits from SSF Research

- **Improved Quality of Life on Earth Resulting from Long-Term Research Capability on SSF**
- **Ensure Safety and Maximize Productivity of Humans in Space**
- **Non-Terrestrial Environment Requires Development of New Materials and Technologies Transferable to Private Sector Industries**
- **Knowledge Gained on Fundamental Processes Applicable to Earth-Based Processing and Technology**
SOME STRATEGIES TO FACILITATE COMMERCIAL SPACE

- Increase private sector awareness of potential areas for commercialization
- Continued contact with private sector companies
- Collaborative research with university researchers
- Dissemination of knowledge gained to scientific community by publications, conferences, seminars, displays.

Education
  - Involvement of students at the intermediate and high school and university levels

PROSPECTS FOR THE FUTURE

Commercial space ventures are expected to increase as the database targets potential profit-making processes and products from microgravity technology development.

- Spending in the area of biopharmaceuticals is increasing.
  - Earth-based spending for biopharmaceuticals by the end of this decade is projected to be in the range of $60 billion, 50 times greater than it is now.

- Cooperative CCDS research in the above mentioned areas is essential for maturing SSF biotechnology

- New technologies are expected to develop and to ensure U.S. leadership in space technology.
INTEGRATION AND USE OF A MICROGRAVITY RESEARCH FACILITY: LESSONS LEARNED BY THE CRYSTALS BY VAPOR TRANSPORT EXPERIMENT AND SPACE EXPERIMENTS FACILITY PROGRAMS

Presented by Barbara L. Heizer
Boeing Defense and Space Group

ABSTRACT

The Crystals by Vapor Transport Experiment (CVTE) and Space Experiments Facility (SEF) are materials processing facilities designed and built for use on the Space Shuttle middeck. The CVTE was built as a commercial facility owned by the Boeing Company. The SEF was built under contract to the UAH Center for Commercial Development of Space (CCDS). Both facilities include up to three furnaces capable of reaching 850°C minimum, stand-alone electronics and software, and independent cooling control. In addition, the CVTE includes a dedicated stowage locker for cameras, a laptop computer, and other ancillary equipment. Both systems are designed to fly in a Middeck Accommodations Rack (MAR), though the SEF is currently being integrated into a Spacehab rack. The CVTE hardware includes two transparent furnaces capable of achieving temperatures in the 850° to 870° C range. The transparent feature allows scientists/astronauts to directly observe and affect crystal growth both on the ground and in space. Cameras mounted to the rack provide photodocumentation of the crystal growth. The basic design of the furnace allows for modification to accommodate techniques other than vapor crystal growth.

Early in the CVTE program, the decision was made to assign a principal scientist to develop the experiment plan, affect the hardware/software design, run the ground and flight research effort, and interface with the scientific community. The principal scientist is responsible to the program manager and is a critical member of the engineering development team. As a result of this decision, the hardware/experiment requirements were established in such a way as to balance the engineering and science demands on the equipment. Program schedules for hardware development, experiment definition and material selection, flight operations development and crew training, both ground support and astronauts, were all planned and carried out with the understanding that the success of the program science was as important as the hardware functionality.

The CVTE payload has been delivered to the Kennedy Space Center and is undergoing final assembly and check-out prior to installation on the orbiter Columbia. It is manifested to fly on STS-2. The SEF is undergoing assembly and checkout prior to environmental testing at the Boeing facility in Kent, WA. It will be delivered to the UAH in early October, 1992.

This presentation will be a discussion of how the CVTE payload was designed and what it is capable of, the philosophy of including the scientists in design and operations decisions, and the lessons learned during the integration process.
Integration and Use of a Microgravity Research Facility: Lessons Learned by the CVTE and SEF Programs

Barbara Heizer
August 5, 1992

Program Overview
Hardware Status
System Requirements
Integration Issues: Lessons Learned
Summary
Crystals by Vapor Transport Experiment
Program Overview

Objectives:

Design, fabricate and assemble a microgravity materials processing facility for use on the Space Shuttle Middeck.

Develop the procedures, staff, experience, and facilities required to integrate complex payloads into a manned space system.

Develop a flexible, user friendly furnace facility capable of providing a stable, programmable thermal environment up to 850°C.

Approach:

Develop cooperative agreements with premier scientists and crystal growers

Select vapor transport crystal growth process

Identify candidate materials for space processing demonstration

Commercially viable
Potential for improved quality
Growth time: $8 \text{ min} < \text{GT} < 2 \text{ days}$
Approach (cont.):

Execute a Joint Endeavor Agreement (JEA) with NASA for microgravity experiments on shuttle flights

Design, develop, and fly hardware to perform these experiments

Expand capabilities to include advanced applications

Technology Application:

Space Systems are a major Boeing product area

Materials processing in space is a prime element of space commercialization

Potential markets exist for space materials processing facilities

Supports Space Station operation and growth
CVTE: Crystals by Vapor Transport Experiment

2-furnace facility with independent electronics and S/W
Transparent furnaces, 2 samples/furnace
Middeck payload

SEF: Space Experiments Facility

2nd CVTE facility being built for the UAH
3-furnace facility; 2 transparent/1 opaque (1050 °C)
Middeck payload
Operational Configuration

On-orbit start up and operation (2 furnaces)
(MAR aft panel removed)

CVTE:
Undergoing final assembly and checkout at KSC
Turnover to KSC personnel August 20
STS-52 launch October 15

SEF:
Environmental test program starts August 10
Demonstration testing in September
Delivery to UAH November 2
Crystals by Vapor Transport Experiment
System Requirements

Transparent Furnace
Temperature repeatability

Furnace to Furnace \( \pm 5^\circ C \)
Coil Setpoint \(< \pm 1^\circ C\)

Provide a suitable environment for growing large single crystals of CdTe

850 °C centerline temperature
Thermal gradient \(10^\circ C/cm < \frac{dt}{dx} < 50^\circ C/cm\)
Centerline temperature variation: Max \(< \pm 0.1^\circ C\)
RMS \(< \pm 0.025^\circ C\)

Pull rate: \(1 \text{ mm/day} < \frac{dl}{dt} < 25 \text{ mm/day}\)
System set-up time not to exceed 30 minutes
Independent electronics, software, and cooling control
Safe operation
Must function in both ground research and flight operation environments
Must meet shuttle middeck environmental requirements
Chief Program Scientist Responsibilities:

- Responsible to the Program Manager
- Not necessarily a PI for the flight
- Primary I/F with science and academic communities

Develop:
- Science requirements
- Ground and flight experiment plans

Provide inputs:
- Engineering design
- Software design

The Chief Scientist must have equal authority to the Chief Engineer.

Principal Investigator Involvement:

- Compatibility with ground and flight H/W required
- Access to the ground and flight hardware prior to flight required
- Time for confidence building between the resident science/engineering team and PI's essential
- PI involvement in crew training, flight procedure development and mission support must be negotiated early in the program
Principal Investigator Involvement:

Conflict between NASA, engineering and science requirements exists. Compromise is critical to program success.

The experiment that is finally flown may not be the original concept due to incompatible requirements.

Be prepared for the cost of flight integration.

Critical integration requirements include:

Safety Reviews
Operation/Procedure Development
Analyses
Crew Training
Qualification Testing

Minimize Rework!
Understand who the players are:

Boeing: Engineering and Science

NASA/HQ: Sponsor

NASA/JSC: Integration

NASA/MSFC: JEA Administration

NASA/KSC: Launch Site Support and H/W Installation

PI: Science

Joint Endeavor Agreement:

JEA is a flawed document for use with a complex payload

No traditional "contractual coverage"

Program advocate or Mission Manager is needed to represent the payload through integration
Flight Documentation Development:

- Establish detailed interface requirements early
- Establish controlling documentation early
- Safety Reviews: Understand which system drives the requirement
- Maintain communication and cooperation with the group responsible for hardware integration

In order to prepare experiments for use on the Space Station the following must be considered:

- Chief Scientist with appropriate authority is key
- Contractual instrument to define requirements is critical
- Program advocate is a plus
- Flexibility to react is essential
- CVTE is a flight ready materials processing facility adaptable to Space Station Freedom.
SESSION 4: CLOSING PLENARY

SPACE STATION FREEDOM UTILIZATION CONFERENCE

AUGUST 6, 1992
A CONGRESSIONAL PERSPECTIVE ON THE SPACE STATION PROGRAM

Presented by Richard M. Obermann
Subcommittee on Space
Committee on Science, Space and Technology
U.S. House of Representatives

ABSTRACT

While a number of factors enter into Congress’ view of the Space Station program, the overall budgetary situation has had a major impact on determining the environment in which consideration of the Space Station program has taken place. The constrained budgetary outlook has driven much of the debate on spending and priorities in Congress this year, and the focus has been on which programs to cut rather than what new programs to start. Although NASA’s overall budgetary request was relatively modest—an increase of less than 5 percent over Fiscal Year 1992—the Space Station Freedom program was the target of Representative’s NASA Authorization bill and the VA/HUD/Independent Agencies appropriations bill. However, the amendments were defeated by comfortable margins on both occasions.

Over the near term, Space Station supporters in the Congress will attempt to achieve a final appropriation for the Space Station that is as close to the President’s request as feasible. Over the longer term, it is vital to the success of the Station program and preservation of a balanced NASA program that the Space Station be affordable to operate and provide the most efficient and effective platform possible for its users. The House Committee on Science, Space and Technology has long been concerned with the potential annual operating costs of the Space Station and has urged NASA to investigate approaches to minimizing those costs.
NASA INCREASES VS. TOTAL DDS AVAILABLE
(DOMESTIC DISCRETIONARY SPENDING)

BILLION DOLLARS

FISCAL YEAR

TOTAL DDS AVAILABLE
NASA INCREASES

NASA BUDGET
(FISCAL YEAR 1993 DOLLARS)

BILLION DOLLARS

FISCAL YEAR

F.Y. 93 REQUEST

SENATE

HOUSE

PRECEDING PAGE BLANK NOT FILMED
CREW EXPERIENCE IN SPACE RESEARCH

Presented by Bonnie J. Dunbar
Astronaut Office
NASA Johnson Space Center

ABSTRACT

Space Shuttle crews train for 18 months per mission; they are assigned to science missions according to their background. Training encompasses preparations for troubleshooting. Astronauts often need to make judgement calls about how investigations will proceed in space; they want to work with investigators on preparing payloads and planning science operations so they will be as familiar as possible with the experiment.

The astronaut office at Johnson Space Center has organized an *ad hoc* science support group to keep abreast of the state of the art in science. The activities of this group support the work of the astronaut office’s mission development group.

Astronauts are already testing space station precursor hardware on Space Shuttle missions, including two types of gloveboxes, and studying onboard vibration disturbances. Thus far, vibration caused by crew exercise has been indistinguishable from the background vibration of 5-10 micro-gs.
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LIST OF ATTENDEES

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HAKA EGOI
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TODD HOLLOWAY
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ALAN C. HOLT
NASA HEADQUARTERS

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<td>Gino M. Mondini</td>
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<tr>
<td>Dina E. Montufar-Solis</td>
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<td>E. Stanley Moorehead</td>
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<td>Frank Morning, Jr.</td>
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<td>Thomas Moser</td>
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<td>Charles W. Mueller</td>
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<tr>
<td>Rob Mueller</td>
<td>UT-Calspan Cstar</td>
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<tr>
<td>Dr. Joy Mulholland</td>
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<tr>
<td>Walter F. Muller</td>
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<tr>
<td>Dr. Richard E. Mullins</td>
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<td>Michael L. Nagy</td>
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<tr>
<td>Ernest B. Nathan</td>
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<td>Dr. Ralph A. Nelson</td>
<td>Carle Foundation</td>
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<td>Charlie M. Newman</td>
<td>TRW</td>
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<td>Roger D. Nichols</td>
<td>McDonnell Douglas</td>
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</table>
MARY LOU NICKLES
MCDONNELL DOUGLAS

JOHN B. NOBLIN
IBM

BOB NOBLITT
TRW

DAVID O'DELL
MARSHALL SPACE FLIGHT CENTER

HERBERT L. O'FALLON
KENNEDY SPACE CENTER

MIKE O'ROURKE
UNISYS

DR. PAT R. ODOM
PRC INCORPORATION

DAVID W. OLIVET
INTERNATIONAL SPACE SYSTEMS, INC.

RONALD A. OLSEN
TELEDYNE BROWN ENGINEERING

DR. BILL OLSON
MCDONNELL DOUGLAS

JOSE ORTIZ
NASA HEADQUARTERS

RICHARD OTT
NASA HEADQUARTERS

JOHN OWENS
MARSHALL SPACE FLIGHT CENTER

ROBERT E. PACE, JR.
PACE & WAITE, INC.

CINDY PARKER
MCDONNELL DOUGLAS

ROBERT PARKER
NASA HEADQUARTERS

JOHN M. PARRISH
TRW

JOHN PARSONS
TRW

SUSAN L. PENFIELD
PRC INCORPORATION

FRANK PEREZ
UNISYS CORPORATION/PARAMAX

JEFF PERKINS
RUSSELL ASSOCIATES

DR. VINCENT L. PISACANE
APPLIED PHYSICS LABORATORY

CELESTE PLAISANCE
BDM INTERNATIONAL, INC.

RODGER L. PLOTNER
HARRIS CORPORATION ELECTRONICS SYSTEMS

DR. ALEXANDER T. POL
UNIVERSITY OF MIAMI

RONALD F. PORTER
MARSHALL SPACE FLIGHT CENTER

LYTHE POWELL

HAROLD L. PRIOR
MCDONNELL DOUGLAS

GLENN PROW
LOCKHEED

DONNA PRSHA
MARSHALL SPACE FLIGHT CENTER

THOMAS RATHZ
UNIVERSITY OF ALABAMA IN HUNTSVILLE

B. THOMAS RECIO
BOEING

WILLIAM F. RECTOR
RECTOR ASSOCIATES INTERNATIONAL, INC.

TRACEY REED
MARSHALL SPACE FLIGHT CENTER

AL REISZ

CHARLES REYNERSON
U.S. NAVY/MIT

MICHEAL A. REYNOLDS
MCDONNELL DOUGLAS

ROBERT C. RHOME
NASA HEADQUARTERS

MICHAEL RICHTER
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JAMES RIDER
TELEDYNE BROWN ENGINEERING

GRADY F. RILEY
BOEING

DR. HARTMUT RIPKEN
DARA

STEVE ROBBINS
MARSHALL SPACE FLIGHT CENTER

JACK E. ROBERTSON
WYLE LABORATORIES

JUDITH L. ROBIE
NASA HEADQUARTERS

PAUL ROBICHAUX
BOEING COMPUTER SUPPORT

MARK ROGERS
MARSHALL SPACE FLIGHT CENTER

MELISSA J. ROGERS
UNIVERSITY OF ALABAMA IN HUNTSVILLE

GARY T. ROSIAK
TRW

HEIDI ROSNER
TRW

WALT ROWE
BOEING

ROBERT L. SANDERS
FAIRCHILD SPACE

WILTON SANDERS
UNIVERSITY OF WISCONSIN

KIMBERLY SANLAND
MARSHALL SPACE FLIGHT CENTER

LIAM P. SARSFIELD
WYLE LABORATORIES

JAMES R. SCHAFFER
BOEING

RICK SCHANSMAN
SCI TECHNOLOGY, INC.

RON SCHLAGHECK
MARSHALL SPACE FLIGHT CENTER

Appendix B-6
LIST OF ATTENDEES

CHUCK SCHLEMM
MIDDLE TENNESSEE SPACE SOCIETY

DR. WILLIAM C. SCHNEIDER
SPACE STATION ADVISORY COMMITTEE

RICHARD SCHUBERT
VITRO

JOYCE SCHULTZ
GE

PAUL SCHWINDT
BOOZ-ALLEN AND HAMILTON

HELMUT SCHWILLE
DORNIER OF NORTH AMERICA, INC.

ROBERT C. SEABROOK
TELEDYNE BROWN ENGINEERING

VALERIE SEAQUIST
UNIVERSITY OF ALABAMA IN HUNTSVILLE

LOU W. SEILER
HARRIS CORPORATION

DANIEL SHAMES
BDM INTERNATIONAL, INC.

MELVYN J. SHICHTMAN
U.S. ARMY LABORATORY COMMAND

MERLIN SHUEY
HAMILTON STANDARD

JAY SIMMONS
MCDONNELL DOUGLAS

DR. FRANK SIX
MARSHALL SPACE FLIGHT CENTER

FRANK A. SLAZER
MCDONNELL DOUGLAS

JEFF SLOSTAD
UNIVERSITY OF WASHINGTON

CLINT SMITH
TELEDYNE BROWN ENGINEERING

DAMON SMITH
LOCKHEED

SCOTT A. SMITH
KRUG LIFE SCIENCES

WAYNE SMITH
BOEING

DR. ROBERT S. SNYDER
MARSHALL SPACE FLIGHT CENTER

DR. DENNIS G. SOCKER
NAVAL RESEARCH LABORATORY

ROBERT J. SODANO
GOODARD SPACE FLIGHT CENTER

SCOTT SPEARING
TELEDYNE BROWN ENGINEERING

E. G. SPIELER
MCDONNELL DOUGLAS

BOB STALLINGS
TELEDYNE BROWN ENGINEERING

JERRY STEBBINS
BOEING

KAREN L. STEPHENS
MARSHALL SPACE FLIGHT CENTER

WILLIAM K. STEPHENSON
NASA HEADQUARTERS

EUGENE STERN
GRUMMAN

ANDREW J STOFAN
ANALEX CORPORATION

LOUISE STRUTZENBER
MARSHALL SPACE FLIGHT CENTER

ARTHUR SULKIN
ROCKWELL INTERNATIONAL

DEXTER SULLIVAN
MARSHALL SPACE FLIGHT CENTER

KAY SUTHERLAND
MARSHALL SPACE FLIGHT CENTER

FRANK SZOFRAM
MARSHALL SPACE FLIGHT CENTER

ANN E. TAYLOR
MARSHALL SPACE FLIGHT CENTER

KENNETH R. TAYLOR
MARSHALL SPACE FLIGHT CENTER

GREG A. THOMAS
TELEDYNE BROWN ENGINEERING

BOBBY J. THOMPSON
MARSHALL SPACE FLIGHT CENTER

WALTER THOMPSON
GENERAL DYNAMICS SPACE SYSTEMS

DAVID L. THRASHER
BOEING

SUSAN TODD
BOEING DEFENSE & SPACE GROUP

JEANETTE TOKAZ
SVERDRUP CORPORATION

DR. LARRY P. TORRE
BOEING

NEIL TOWNSEND
LOCKHEED

WANDA C. TOWRY
MARSHALL SPACE FLIGHT CENTER

AL TRUESDALE
LORAL AEROSYS

JERRY H. TUCKER
LANGLEY RESEARCH CENTER

WALLACE B. TWICHELL
TELEDYNE BROWN ENGINEERING

ANDREW P. TYGIELSKI
TELEDYNE BROWN ENGINEERING

JAMES M. VAN ALSTINE
USRA

WILLIAM K. VARDAMAN
RANTEK INCORPORATED

CHUCK VEDANE
TELEDYNE BROWN ENGINEERING

A. A. TONY VERRENGIA
GE GOVERNMENT SERVICES

FELMINIO VILLELLA
MARSHALL SPACE FLIGHT CENTER

FRANK L. VINZ
LORAL

EDWARD C. VOETEN
BRADFORD ENGINEERING

ROBERT M. VUOLO
JET PROPULSION LABORATORY

Appendix B-7
LIST OF EXHIBITORS
SPACE STATION FREEDOM UTILIZATION CONFERENCE

Space Station Freedom Utilization Conference
Boeing
Canadian Space Agency
Grumman
McDonnell Douglas
NASA Ames Research Center
NASA Johnson Space Center
NASA Marshall Space Flight Center
NASA Headquarters Office of Aeronautics and Space Technology
NASA Headquarters Office of Commercial Programs
NASA Headquarters Office of Space Flight
NASA Headquarters Office of Space Science and Applications
National Space Development Agency of Japan
Rockwell
Rocketdyne
Spacehab
Teledyne Brown
Wyle Laboratories

Payload Data Services Workshop
Avyx Incorporated
Barrios Technology
Boeing
Gulton Data
Harris Space Systems
Honeywell
IBM
McDonnell Douglas
NASA Kennedy Space Center
NASA Marshall Space Flight Center
NASA Headquarters Scientific and Technical Information Office
NASA Headquarters Office of Aeronautics and Space Technology
SBS Engineering
Southwest Research Institute
Speedring
Texas Instruments
LIST OF EQUIPMENT
SPACE STATION FREEDOM UTILIZATION CONFERENCE

Laboratory Support Equipment (LSE)
- Battery Charger
- Cameras and Locker
- Camera (video) and Lights (set)
- Cleaning Equipment
- Digital Recording Oscilloscope
- Digital Multimeter
- Digital Thermometer
- EM-shielded Locker
- Film Locker
- Fluid Handling Tools
- Freeze Dryer
- Freezer, -20°C
- Freezer, -70°C
- Freezer, Cryogenic Quick/Snap
- Freezer, Cryogenic Storage
- General Purpose Hand-tools
- Glovebox, Portable
- Macroscope, Stereo (includes video camera)
- Mass Measuring Device, Micro
- Mass Measuring Device, Small
- Microgravity Science Glovebox
- Passive Dosimeter, Reader/Annealer
- pH Meter
- Specimen Labels

General Laboratory Support Facilities (GLSF)
- Life Sciences Glovebox
- Materials Processing Glovebox

Appendix D-1
Summary

The Payload Data Services (PDS) Workshop was held on August 4-7, 1992 at the Von Braun Civic Center in Huntsville, Alabama. The workshop was sponsored by the Office of Space Systems Development to provide detailed engineering and operations information for Space Station Freedom (SSF) payload developers. Along with detailed hardware, software, and operations presentations, exhibits of commercially- and NASA-developed systems were displayed and demonstrated. The exhibits ranged from hardware and software systems to integration and information system services. The combination of presentations, demonstrations, and exhibits provided the payload community with current engineering details to enable them to effectively plan, develop, and implement their payload Data Management System (DMS) interfaces.

The Space Station Freedom Program Office initiated the workshop with a conceptual overview of SSF payloads and the DMS. Other introductory presentations addressed the major elements that play a role in supporting payload DMS activities, such as Communications and Tracking, the Space Station Control Center, the Payload Operations and Integration Center, and the Payload Data Services System. Additional presentations on payload operations and data flow concepts highlighted the contexts within which the payloads must operate. These operational scenarios provided payload developers with an understanding of how to interact with the DMS and what to expect from ground support equipment, data manipulations, and general operations.

An overview by McDonnell Douglas Space Systems Corporation (MDSSC) initiated the detailed baseline hardware presentations. This was followed by presentations from each hardware contractor (IBM, Honeywell, etc.) These presentations walked the payload developers through increasingly lower levels of detail covering all functional, mechanical, and electrical elements of DMS hardware. Included in the briefings were functional block diagrams, data flow concepts, schematics, and engineering drawings. The hardware presentations were followed by demonstrations on the various development kits available through the SSF program. Also, an ad hoc presentation was given by a representative of the Johnson Space Center on the status of the Engineering Design Council activity and by the Marshall Space Flight Center on the status of the Payload Analytical Integration process.

The second day of the PDS Workshop started with an MDSSC overview of DMS software elements in each of the hardware components. These briefings addressed DMS interfaces, Object Model, and the general software architectures. Lower level, detailed briefings were given by IBM, Honeywell, and MDSSC that covered various aspects of the DMS software, including telemetry services, file services, and Runtime Object Data Bases. A presentation also was given on Timeliner by Draper Laboratories that addressed the automated operations capability of SSF.

The remainder of the second day's agenda addressed ancillary DMS activities. These included a discussion of the SSF's video architecture and capabilities, a Technical and Management Information System demonstration on how payloads can obtain engineering data, a presentation on the Office of Aeronautics and Space Technology's Data System Technology program and its relationship to the SSF, and a presentation on the Astronaut Science Advisor, which is an intelligent software application that optimizes payload operations.

Day three of the PDS Workshop focused on customized payload systems. The Payload Executive Software (PES) was presented by representatives of the Marshall Space Flight Center. They outlined the functions and operations of the PES and provided payload developers with insight into the implications of the various command and control connectivity options available to them. The following presentation addressed the specifications and designs for Freedom's onboard displays and controls. The Payload Data Services System was then presented. The manner in which it will link principal investigators, mission specialists, managers, local and remote facilities, the Space Station Control Center, and the SSF was described.
The final day's afternoon sessions involved presentations and demonstrations by Ames Research Center, Marshall Space Flight Center, and Honeywell representatives on various aspects of potential payload computers and development tools. Special presentations from Ames Research Center representatives addressing other payload-related data studies also were given.

The PDS Workshop concluded by generating action items addressing current and future payload DMS issues. Also, the participants overwhelmingly agreed the workshop should be repeated in the future to serve as a tool for educating the payload community and other user-oriented organizations, such as the Space Station Science and Applications Subcommittee.
PAYLOAD DATA SERVICES WORKSHOP

AGENDA

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<tr>
<th>August 4</th>
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<tr>
<td>8:00</td>
<td>Registration</td>
<td>Payload Executive Software (PES)</td>
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<td>9:00</td>
<td>Payload Software DMS Interfaces</td>
<td>Displays and Controls</td>
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<td>10:00</td>
<td>Opening Remarks</td>
<td>Payload Data Services System (PDSS)</td>
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<td>11:00</td>
<td>DMS Overview</td>
<td>Portable Computer Commonality Study</td>
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<td>Ground Operations Accommodations</td>
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<td>SSF Data Flow</td>
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<td>Operations Orientation</td>
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<td>Payload Hardware DMS Interfaces</td>
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Reception at Space Camp
7:00 - 9:00 PM

Appendix E-3