

SPACE STATION FREEDOM UTILIZATION CONFERENCE

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



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FREEDOM UTILIZATION CONFERENCE.
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EXECUTIVE SUMMARY

6-11

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SPACE STATION FREEDOM UTILIZATION CONFERENCE

*VON BRAUN CIVIC CENTER
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AUGUST 3-6, 1992*

Sponsored by:

*Space Station Freedom Program
NASA Headquarters
Washington , D.C.*

EXECUTIVE SUMMARY

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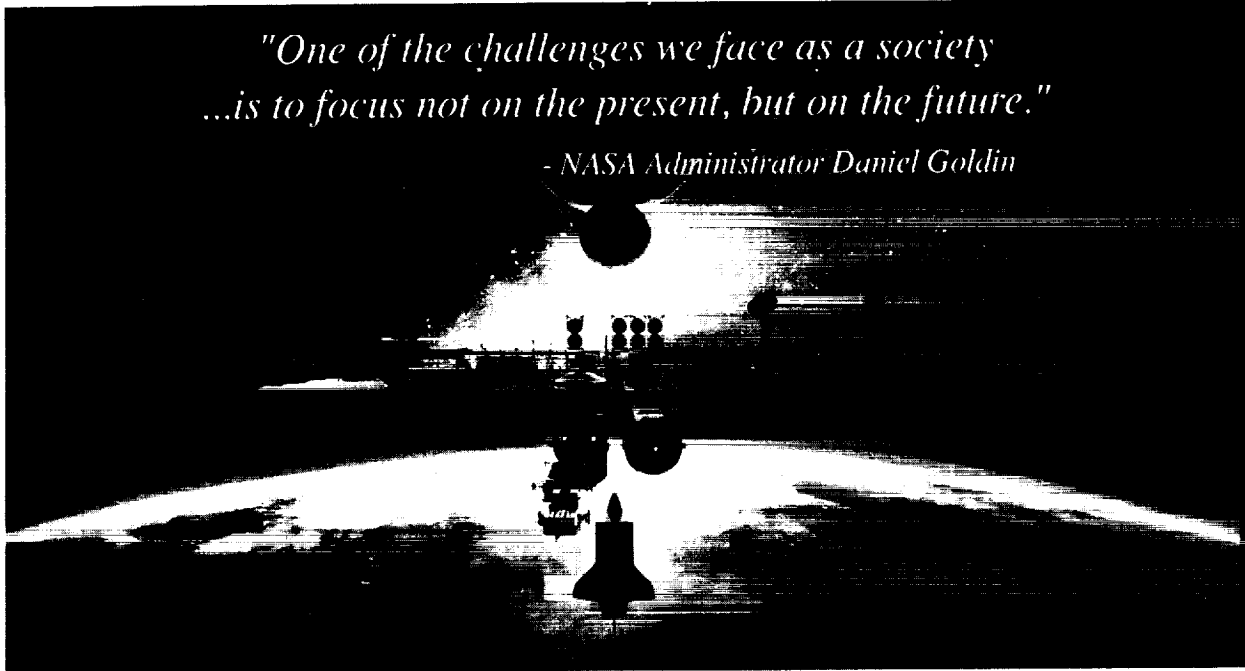
SPACE STATION FREEDOM UTILIZATION CONFERENCE

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EXECUTIVE SUMMARY

SPACE STATION FREEDOM UTILIZATION CONFERENCE



*"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 A.)

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.

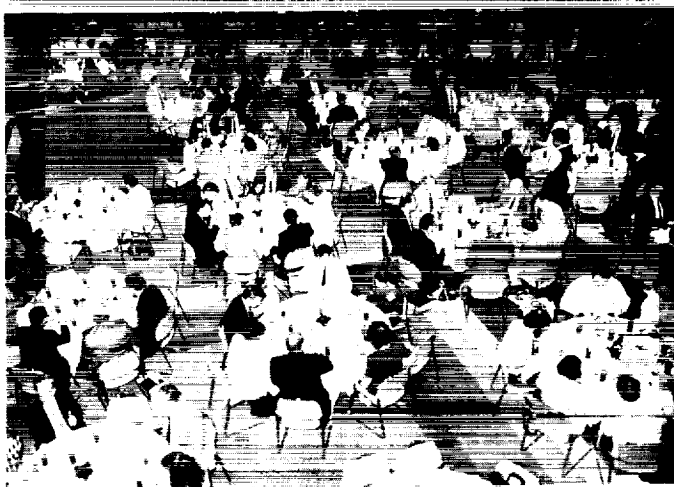
In plenary and splinter sessions, speakers described space station capabilities, plans and opportunities for research. Freedom will accommodate experiments in its laboratory modules and observational payloads mounted external to the modules. It will provide researchers access to the microgravity environment 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' Wakefield 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 I (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.



Participants enjoyed the Welcome Lunch.

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:

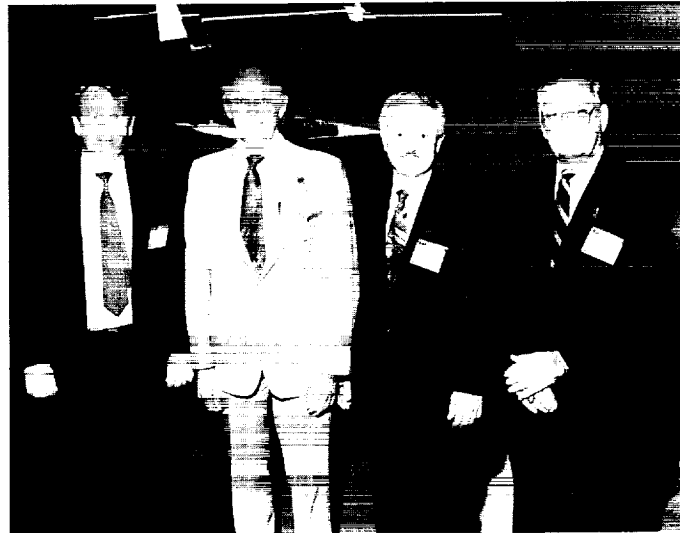
NASA field centers and contractors are organized to develop "work packages" for Space Station Freedom. Marshall Space Flight Center and Boeing are building the U.S. laboratory and habitation modules, nodes, and environmental control and life support system; Johnson Space Center and McDonnell Douglas 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



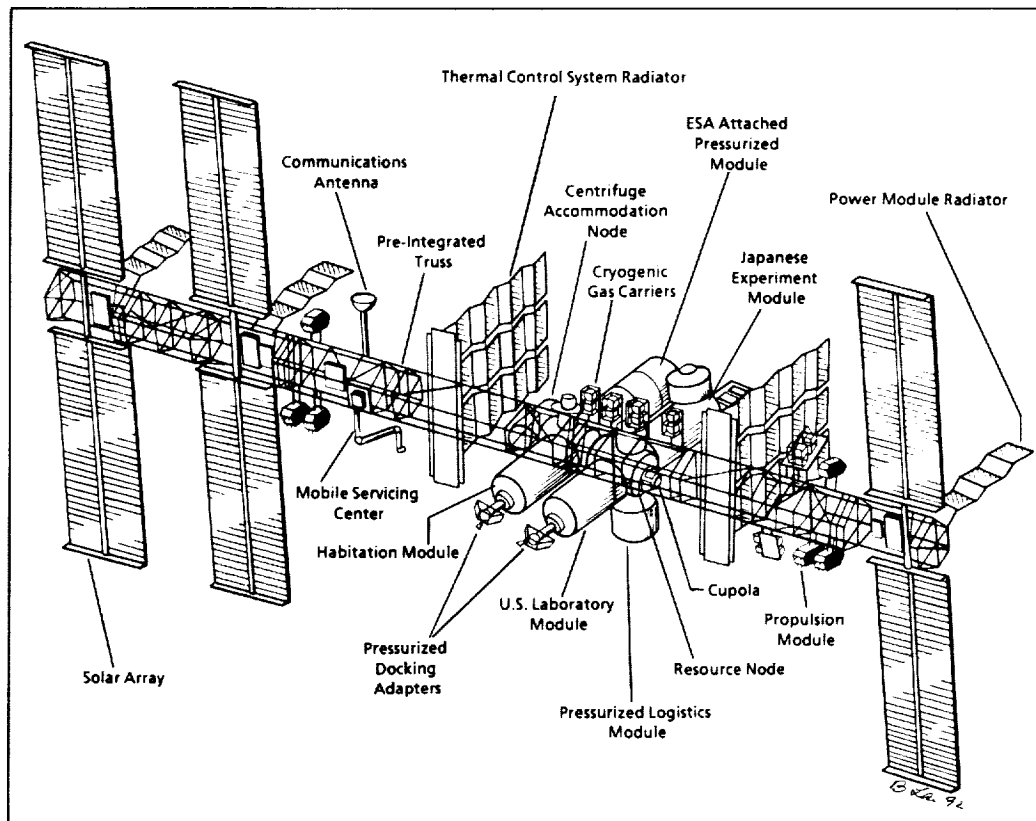
Opening Plenary Speakers: Robert Moorehead, Robert Phillips, John-David Bartoe and Richard Kohrs.

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



Permanently Manned Capability (PMC).

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.

MICROGRAVITY RESEARCH
<ul style="list-style-type: none"> • Materials Science <ul style="list-style-type: none"> - Electronic and photonic materials - Metals, alloys and composites - Glasses and ceramics • Fundamental sciences <ul style="list-style-type: none"> - Fluid dynamics and transport phenomena - Combustion science - Gravitational physics • Biotechnology Experiments <ul style="list-style-type: none"> - Macromolecular crystal growth
LIFE SCIENCES RESEARCH
<ul style="list-style-type: none"> • Crew health, safety and productivity <ul style="list-style-type: none"> - Monitor crew health - Develop countermeasures to adverse effects of prolonged exposure to low gravity • Basic and applied research <ul style="list-style-type: none"> - Study effects of gravity on living systems - Cell and tissue growth - Biologically based support systems
TECHNOLOGY RESEARCH
<ul style="list-style-type: none"> • Space Construction • Structural dynamics and control • Space materials and environmental effects • Space power systems • Thermal management • Fluid management • Propulsion • Automation and robotics • Sensors • Information systems • Human systems engineering

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.

SPACE STATION RESEARCH CAPABILITIES AT PERMANENTLY MANNED CAPABILITY (~2000)

- 3 Laboratory Modules
- 1 Habitation Module
- 2.5 m (8.2 ft) Centrifuge Facility
- Pressurized working environment
- 42 International Standard Payload Racks
- For Payloads:
 - Power - 30 kW
 - Thermal Control - 30 kW
 - Data Transmission Rate - 50 Mbps
- A permanent crew of 4 with 2 dedicated to research
- 4 attachment points to truss for external payloads
- 10 locations for external payloads on JEM Exposed Facility (zenith, nadir, wake viewing)

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 (CCDSs).

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

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



Inside the U.S. Laboratory Module.

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.

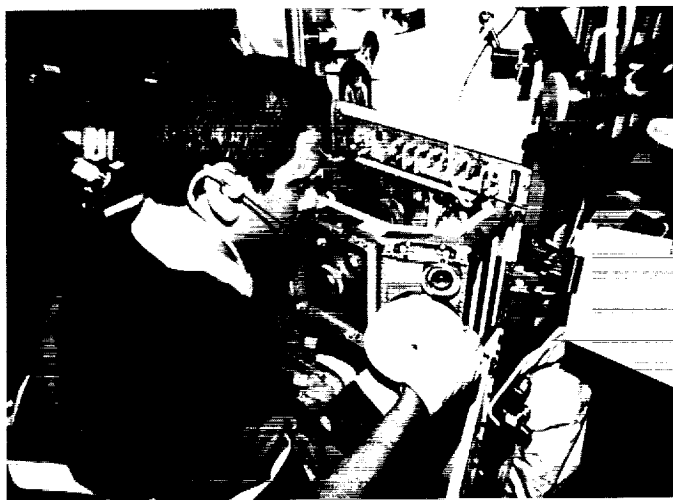
The Microgravity Science and Applications Division has outlined its utilization strategy as follows: Phase 1, provision of transitional

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.



Payload Specialist Larry DeLucas working at the Multipurpose Glovebox.

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



NASA Administrator Daniel Goldin presenting his Keynote Address.

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.

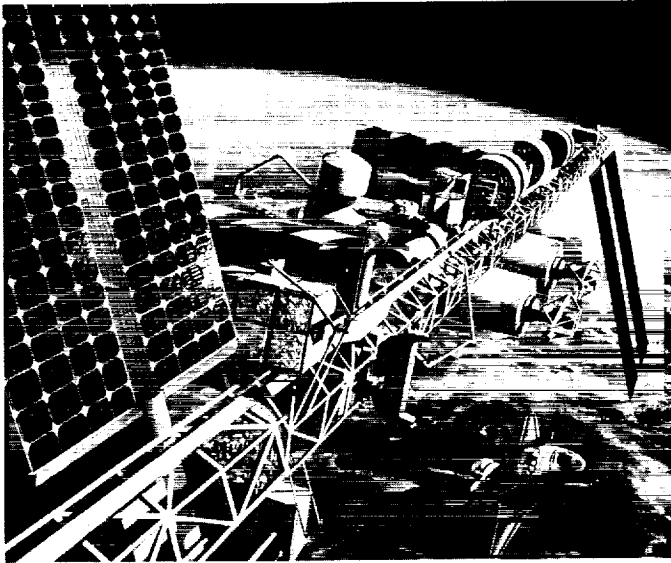
He wrote later on, "I was struck by the contrast of their different approaches to life. Where the armadillo never looks up — concentrating only on its next meal, and oblivious to the world around it — the eagle soars quietly and majestically. It is not rooting around the ground, but is striving for the 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



Artist's Concept of Space Station Freedom and Space Shuttle.

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 Toshio 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.

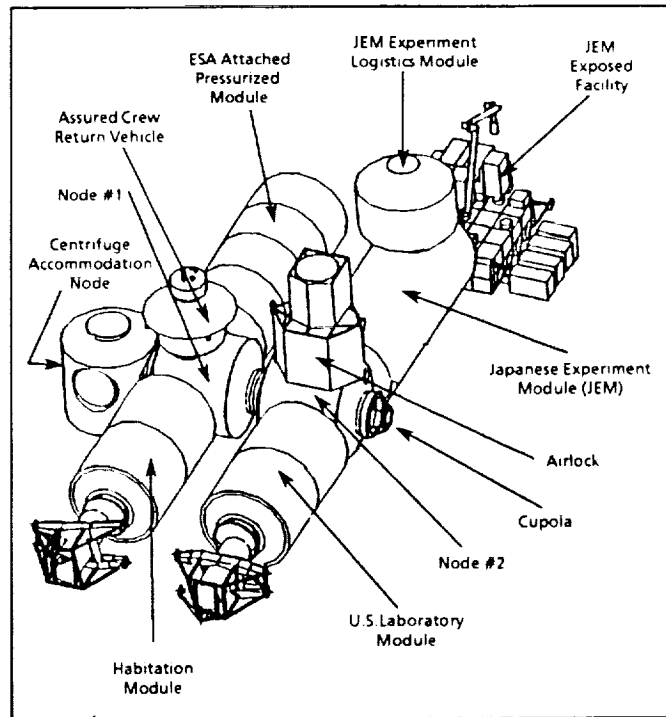
Japan is in the process of implementing a joint research plan under which core research institutes such as the Institute for Space and Astronautical Science (ISAS) will manage space-based investigations, with NASDA providing flight hardware and flight opportunities.

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. NASDA has installed a telescience test bed at its Space Experiment Laboratory, which became operational at the Tsukuba 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



Pressurized Elements (PMC).

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.

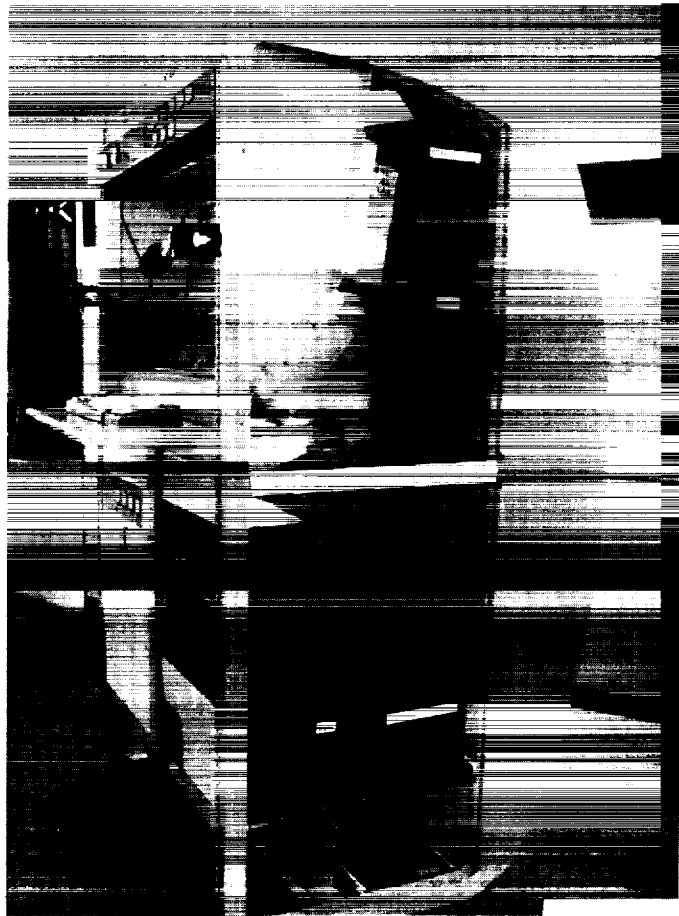
CSA's first solicitation of interest in space station research drew more than 130 responses, including 52 percent for materials science investigations and 17 percent for biology and life science experiments. In evaluating these proposals, discipline review panels will consider factors such as commercial 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.

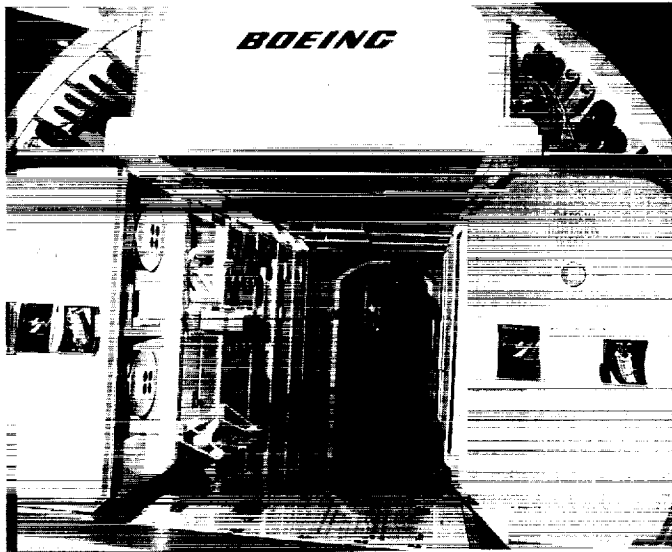
ESA is considering the addition of an external viewing platform to Columbus for attached payloads: the structure will be based on that of ESA's Eureka free-flying platform. As part of its plans for developing space-based investigations so that they will not burden crew members with routine tasks, ESA 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



Mock-up of U.S. Laboratory Module presented by Boeing Corporation.

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 Optzone 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.



Life Sciences Research Splinter Session Chairman Larry Chambers.

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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



Life Sciences research aboard the Space Shuttle.

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.

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**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.

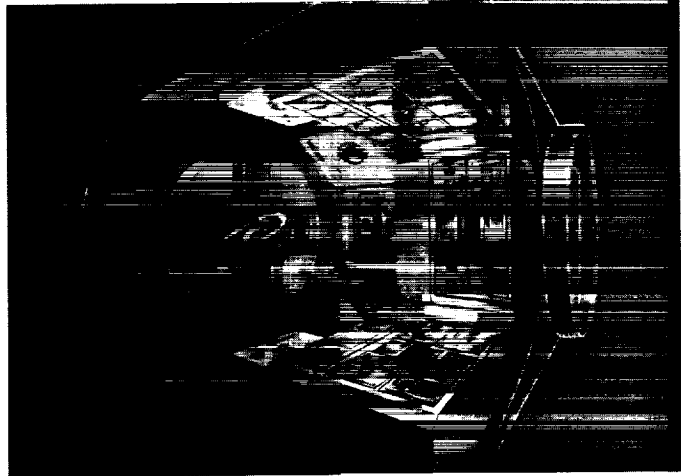
Researchers have gone as far as they can on Earth with studies of the processes by which the solar system and the universe were formed. The microgravity environment of Space Station Freedom will increase particle suspension times, reduce interference from buoyancy-driven convection, and enable the study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



A Space Station node will accommodate the 8.2 ft. diameter centrifuge.

The CFP is generic hardware, but it is being designed to accommodate experiment-unique equipment such as special specimen chambers or video cameras. However, CFP experiment proposals, to be solicited by NRA, must minimize experiment-unique equipment needs. CFP design studies are complete. Engineering and construction will begin next year.

Early CFP experiments must produce data that meet NASA's flight-verification needs. An NRA for experiments to fly during this flight verification period is due out in 1994; experiments will be selected for flight in 1995. An NRA for ongoing CFP science investigations will be issued in 1997, with experiment development beginning in 1998.

**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



*Technology Research Splinter Session Co-Chairman
M. Frank Rose.*

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.



Technology Research Splinter Session Co-Chairman Roger A. Breckenridge.

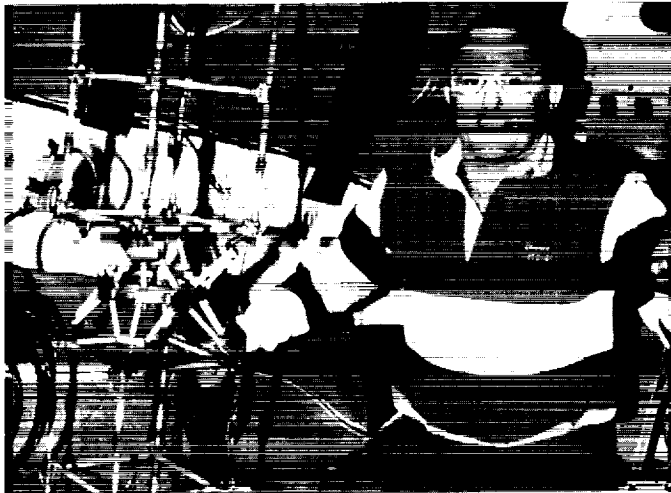
Lessons learned from the IN-STEP Program are that low cost experiments are possible; integrating a space experiment is an art, not a science; the flight crew can be an important part of an experiment's success if properly trained (the crew needs as much hardware interaction during training as possible); 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



Mission Specialist James Buchli operates the Middeck 0-gravity Dynamics Experiment (MODE) aboard the Space Shuttle.

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 (SAMPIE) will determine the environmental effects of low Earth orbit on solar cells. SAMPIE 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 data base 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.



MSFC exhibit presenting space station payload operations.

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 fluids 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.



Microgravity Research Splinter Session Co-chairman Robert Bayuzick.

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.

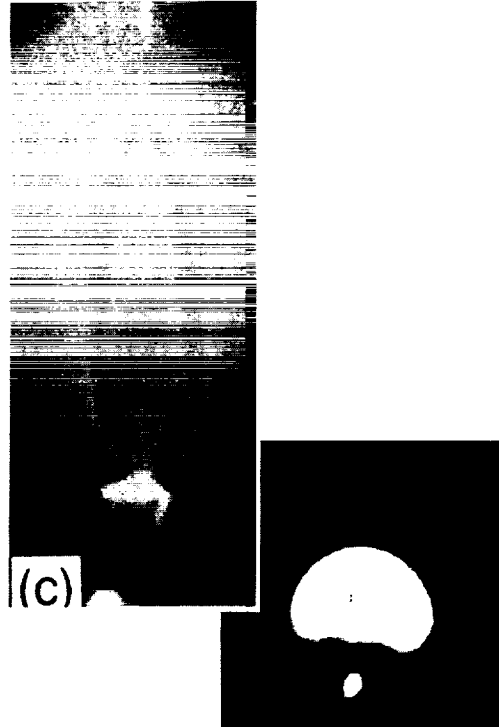
A payload adapter may be available to accommodate small- to moderate-scale microgravity experiments. NASA will begin operating microgravity research facilities during space station assembly (crew tended capability). NASA's research program will involve significant collaboration with the international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



Compare the spherical shape of a flame in microgravity (right) with that of a flame on Earth (left).

the way of a rational merging of theory, in which buoyancy is of little interest, and experimentation, which always is contaminated by buoyancy.

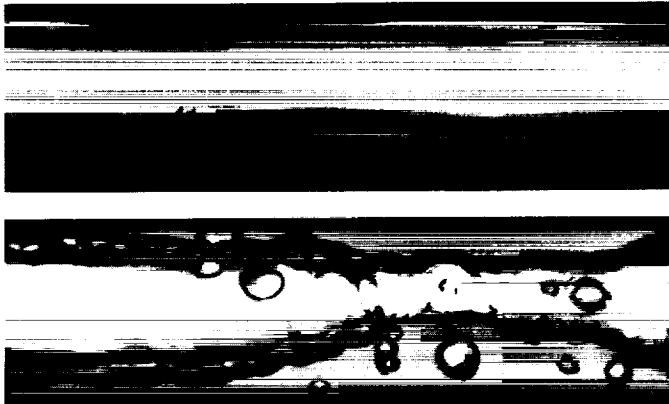
NASA-sponsored microgravity combustion investigations are using both ground- and space-based facilities. Experiments planned for space-based facilities involve laminar premixed flames, soot processes in laminar jet diffusion flames, the structure of laminar and turbulent jet diffusion flames, solid surface 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. Addi-

tional 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):

NASA's Office of Commercial Programs supports space research that meets the needs of U.S. industry, mainly through cosponsorship of a national network of Centers for the Commercial Development of Space (CCDSs). A major objective of the CCDSs is to produce a body of knowledge and experience that will allow U.S. industries to make informed decisions regarding participation in commercial space endeavors. Companies that wish to work more independently with NASA may negotiate Joint Endeavor Agreements or commercial reimbursable agreements. Each type of agreement entails different types and levels of risks for the parties to it.

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



Protein crystals grown on Earth.

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.



Protein crystal grown in microgravity.

Center for Cell Research Director Wesley Hymer (Penn State University):

The goal of the Center for Cell Research (CCR) is to encourage industry-driven

biomedical/biotechnology space projects. The CCR focuses on commercial product- and process-oriented biomedical/biotechnology projects in physiological testing, bioseparations, and illumination. Space-based physiological testing involves animal subjects, tissues or cells for pharmaceutical testing, and research into ground-based health problems.

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-flight 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 commer-

cial products. The project is a collaboration among industry, university and government researchers. The consortium is contacting potential researchers in the biotechnology and pharmaceutical industries.



Conference participants at NASA's Office of Commercial Programs exhibit.

***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. ♦



Astronaut Bonnie Dunbar and Congressional Science Advisor Richard Obermann.

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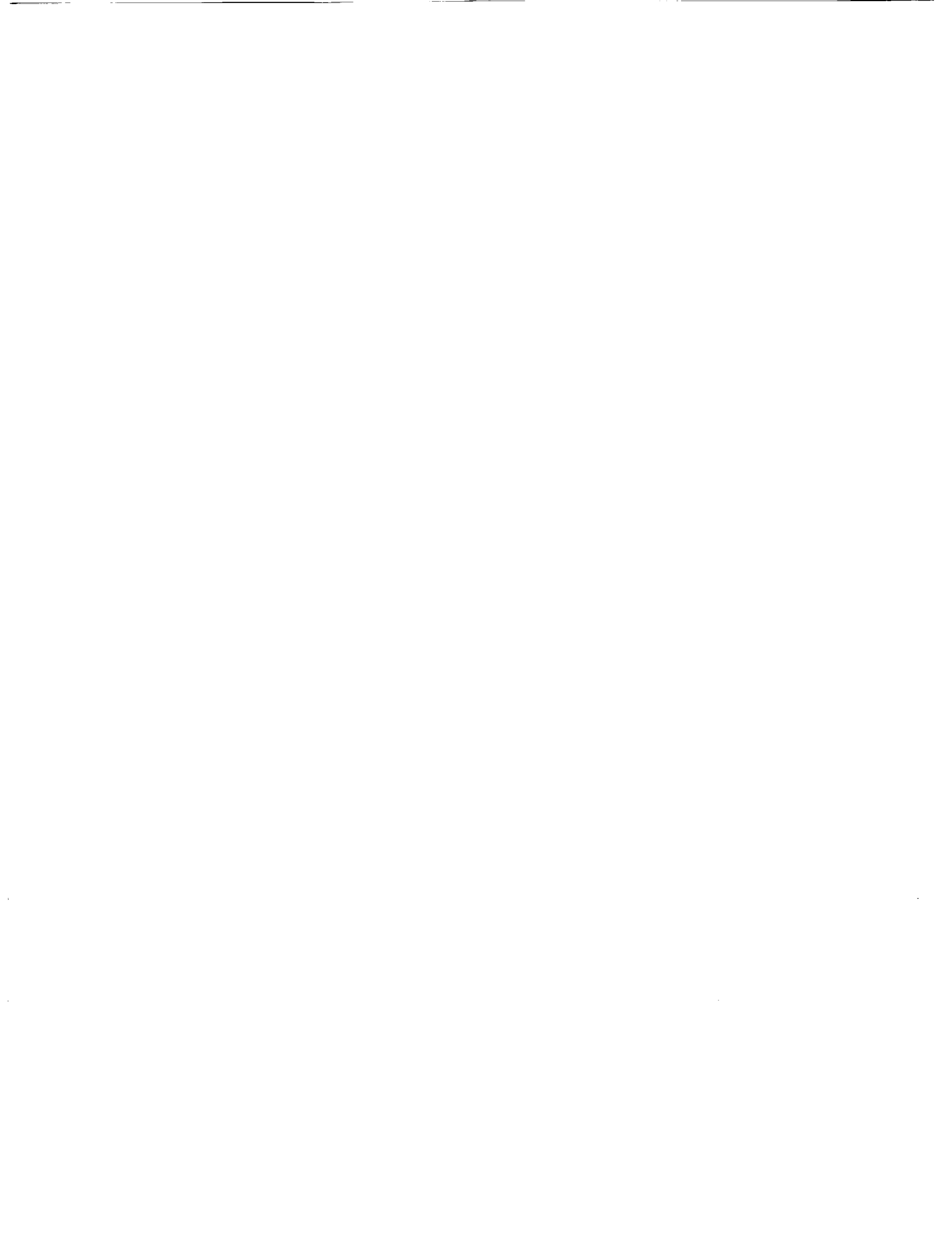
SPACE STATION FREEDOM UTILIZATION CONFERENCE

Space Station Freedom Utilization Conference

Boeing
Canadian Space Agency
Grumman
McDonnell Douglas
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NASA Marshall Space Flight Center
NASA Headquarters Office of Aeronautics and Space Technology
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NASA Headquarters Office of Space Science and Applications
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Wyle Laboratories

Payload Data Services Workshop

Avyx Incorporated
Barrios Technology
Boeing
Gulton Data
Harris Space Systems
Honeywell
IBM
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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



How to Get On Board Space Station Freedom

Technology Development Opportunities

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

NASA Headquarters: (202) 358-0000

For General Information About Space Station Freedom Research Capabilities and Opportunities:

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User Integration Division/Code MG
Spacelab/Space Station Utilization Program
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Science and Applications Opportunities

*Dr. Roger Crouch
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