Paper Session II-B - Past and Future Payloads for the National Aeronautics and Space Administration's Microgravity Science and Applications Program

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Abstract

The National Aeronautics and Space Administration's (NASA) Microgravity Science and Applications Program sponsors basic and applied scientific investigations requiring reduced or near-zero gravity conditions. The absence of gravity-induced phenomena such as buoyancy-driven convection, sedimentation, and hydrostatic pressure in experiments conducted in space provides a unique opportunity to obtain valuable insights into a wide variety of physical processes and materials. Knowledge gained from experiments conducted in space improves our understanding of scientific principles and phenomena, which can, in turn, provide important contributions to Earth-based technology and manufacturing processes. This paper provides an overview of NASA's Microgravity Science and Applications Program, with an emphasis on recent flight activity and planned future utilization of Shuttle, Spacelab, and Space Station Freedom.

Introduction

The objective of the NASA Microgravity Science and Applications Program is to utilize space as a laboratory to expand man's knowledge of the basic sciences, to understand the role of gravity in materials processing, and to support research demonstrating the feasibility of space production of improved materials with high technological utility. Experimenters seek observations of complex phenomena and measurements of physical attributes with a precision enhanced by the microgravity environment; their results will be used to challenge and validate contemporary scientific theories. They seek fundamental insights leading to a better understanding of Earth-based processes and the space-based production of limited quantities of new materials with unique properties. In pursuing these objectives, researchers hope to develop tools, techniques, and procedures that can use the characteristics of space to address important scientific and technological questions, thereby contributing to maintaining the United States' technological competitiveness in global markets and economic health.

The Microgravity Science and Applications Program consists of two major parts; the ground-based (Research and Analysis) program and the flight program. Transition to flight experiment status occurs after ground-based research and testing demonstrate sufficient technical maturity to assure that science objectives can be met in space with a high probability of success.

Ground-based drop tubes and towers, parabolic aircraft, sounding rockets, and Shuttle flights currently provide the infrastructure supporting the microgravity research community. Space Station Freedom will represent a substantial addition to this infrastructure. The current program strategy emphasizes the use of Shuttle, with a transition to Space Station Freedom in the mid to late 1990's. However, retaining carrier flexibility, including the continued use of sounding rockets and future use of free flying spacecraft, remains a program priority.
Goals of the NASA Microgravity Program

The NASA Microgravity Program studies the nature of physical, chemical, and biological processes in a low-gravity environment and applies these studies to advance science and applications in such fields as fluid physics, materials science, combustion science, space biology and medicine, and biotechnology. The goals of the program are to:

- Develop a low gravity research program focused in the areas of biotechnology, combustion, fluid physics, materials science, and selected investigations of other phenomena that require a microgravity environment.
- Foster an interdisciplinary community to promote synergy in carrying out the research program.
- Enable the research through the development of an appropriate infrastructure of flight- and ground-based facilities to meet the science requirements.
- Exchange scientific and technological advances within the governmental, industrial, and academic communities.
- Increase U.S. research opportunities through international cooperative efforts.

Program Strategy

NASA relies on the National Research Council’s Space Studies Board (SSB) to develop research strategies for each of the major space research disciplines. These strategies serve as a guide for NASA as it plans its space research program. Of particular significance to the microgravity research community is the fact that the Space Studies Board has created a new standing committee — the Committee on Microgravity Research — which recently concluded that the microgravity field as a whole has reached a state of maturity and readiness for the development of a comprehensive long-range research strategy. The Space Studies Board has chartered the Committee on Microgravity Research to develop this strategy.

In addition to the Space Studies Board and its Committee on Microgravity Research, the Microgravity Science and Applications Division solicits recommendations from other advisory bodies, including NASA's Space Science and Applications Advisory Committee and the Microgravity Science and Applications Division's Science Discipline Working Groups. These advisory bodies meet periodically to review the progress of the program, reassess the needs of the scientific community, and recommend particular lines of research which will benefit from investigations conducted under reduced-gravity conditions.

Given an identified set of research priorities, the Microgravity Science and Applications Division uses Announcements of Opportunity (AO's) and NASA Research Announcements (NRA's) to solicit research proposals in specific scientific disciplines. Through the announcement process, NASA offers scientific researchers the opportunity to propose ground-based and flight experiments, and makes available the use of U.S. and internationally developed instruments to conduct research. The Division recently selected 121 proposals submitted in response to its "Microgravity Materials Science," "Microgravity Fluid Dynamics and Transport Phenomena," "Microgravity Biotechnology," and "Microgravity Fundamental Science" NRA's.

In 1992, NASA’s Microgravity Science and Applications Program conducted more peer-reviewed, hands-on U.S. microgravity science research in space than cumulative on-orbit U.S. microgravity science since Skylab (1974-1975). In January 1992, NASA completed a very successful first International Microgravity Laboratory (IML-1) mission. This was followed by another extremely successful mission, the first United States Microgravity Laboratory (USML-1) in July 1992. Spacelab-J, a joint Japanese/U.S. mission, successfully completed a September 1992 mission, and in
October 1992 the first in the series of United States Microgravity Payload missions (USMP-1) was successfully completed.

Continued opportunities for space experimentation will be made available through the planned International Microgravity Laboratory (IML), United States Microgravity Laboratory (USML), Microgravity Science Laboratory (MSL), and United States Microgravity Payload (USMP) series of Shuttle missions, and via the International Space Station Freedom. To complement flight opportunities offered by the Space Shuttle and Space Station Freedom, the Microgravity Science and Applications Division will take advantage of additional carriers, including suborbital sounding rockets and free flying spacecraft launched from the Space Shuttle or from expendable launch vehicles. The ability of each of these options to meet the needs of the scientific community will be evaluated in the context of cost effectiveness, practicality, and benefits to the overall research program.

One of the key factors required for maintaining an aggressive, focused Microgravity Science and Applications Program is providing the tools and support base for characterizing the microgravity environment. The Microgravity Science and Applications Division currently sponsors development and operations of Lewis Research Center's Space Acceleration Measurement System (SAMS), which provides an acceleration measurement and recording service for Shuttle payloads. The Division also sponsors Marshall Space Flight Center's Acceleration Characterization and Analysis Project (ACAP), which supports investigators by using the data generated by SAMS and other acceleration monitoring devices to provide predictive assessments and actual reports on the acceleration environments provided on those Shuttle missions supporting microgravity research. Continued SAMS and ACAP support are planned for Space Station Freedom era microgravity researchers.

Ground-Based Program Status

The primary functions of the Microgravity Science and Applications Division's ground-based research and analysis program are to develop research concepts leading to flight experiments, to determine the limitations of various terrestrial processing techniques, and to provide analysis and modeling support to the flight program. New ideas are typically pursued via initial feasibility studies, followed by detailed ground-based laboratory investigations. This approach allows experimental hypotheses to mature prior to evaluation for flight readiness.

In fiscal year 1993, NASA is sponsoring a $17.5M ground-based Microgravity Science and Applications research program, with grants at NASA and other government laboratories, universities, and private industry. These grants support research in the fundamental sciences, including studies of gravitational theory, critical point behavior at low and ambient temperatures, fluid and interfacial transport phenomena, and combustion science in microgravity. They support research in materials science, including the processing of electronic and photonic materials, metals, alloys, composites, glasses, ceramics, and polymers. In the area of biotechnology, the grants support ground-based protein crystal growth research, electrophoresis, the analysis of electrohydrodynamic effects on electrophoretic processes, and cell-science research.

NASA supports its microgravity research program with specialized ground-based facilities to complement the available space flight opportunities. Drop towers, drop tubes, and aircraft provide reduced-gravity conditions for limited time periods. At the Lewis Research Center, NASA maintains both a 30 meter, 2.2 second drop tower, and a 145 meter, 5.1 second drop tower. The Marshall Space Flight Center maintains a 100 meter, 4.5 second drop tube. The Lewis Research Center Learjet and the Johnson Space Center's KC-135 aircraft are also utilized by researchers seeking limited duration reduced gravity conditions.

Flight Program Status

In fiscal year 1993, NASA is sponsoring a $152.8M Microgravity Science and Applications flight program. Near-term efforts focus heavily on completing development, test, and evaluation (Phase
C/D) activities and delivering flight hardware to the Kennedy Space Center in preparation for the 1994 IML-2 and USMP-2 missions, and on selecting the payload complement for the 1995 USML-2 mission. Several payloads planned for Microgravity Science Laboratory (MSL) Spacelab flights in 1997 and 1998 and for early Space Station utilization are in the detailed design and brassboard development stages (Phase B). Additionally, project teams formed in response to the 1992 NRA selections are working with the new PIs to conduct preliminary (Phase A) concept designs and breadboard developments.

NASA enjoyed an extremely successful IML-1 mission aboard the Space Shuttle Discovery (STS-42) in January 1992. The IML-1 mission, the first in a series of missions dedicated to the study of life and materials sciences in microgravity, supported forty-two investigations. More than 200 scientists from nineteen countries participated in the mission. Early results are promising: X-ray measurements of the space-grown triglycine sulfate crystals, grown in NASA's Fluids Experiment System, indicate very uniform growth in space. Preliminary data for the infrared detectors fabricated from the flight crystals indicate improved detectivity as compared to ground-based crystals. A good quality single crystal of mercuric iodide was grown (14 x 12 x 9 mm³) in NASA's Vapor Crystal Growth System. Structural analysis indicates excellent structural homogeneity throughout the crystal. Preliminary results from the Casting and Solidification Technology experiment performed on NASA's Fluid Experiment System have been very encouraging. Flight solidification rates of ammonium chloride (used to model alloy solidification processes) reached a steady state more quickly in microgravity due to minimized convection, the rates exceeded those at Earth's gravity by a considerable factor, and the number of grains formed in microgravity was much less than what is seen in Earth-based systems. This information will help researchers to improve theoretical models of alloy solidification processes. Four of the thirteen crystal sets from NASA's Protein Crystal Growth experiment yielded x-ray diffraction data better than the best known Earth-grown crystals, and the Satellite Tobacco Mosaic Virus protein crystals grown in the German Aerospace Research Establishment (DLR) developed Cryostat were of exceptional size and quality.

USML-1, the first totally U.S. sponsored mission dedicated to microgravity research, was the first in a series of planned missions to establish a program with the long-term continuity required to assure United States preeminence in microgravity science and technology. USML-1, which flew aboard Columbia (STS-50) in July 1992, represented a cooperative effort between U.S. government, industry, and academia. It successfully supported thirty-one investigations in fluid dynamics, crystal growth, combustion, biotechnology, and technology demonstrations. Eleven facilities were used, including three major new facilities making their debut on the mission: the Marshall Space Flight Center developed Crystal Growth Furnace, the Lewis Research Center developed Surface Tension Driven Convection Experiment, and the Jet Propulsion Laboratory developed Drop Physics Module. USML-1, the longest shuttle flight to date at 13 days, 19 hours, and 31 minutes, set the stage for future Extended Duration Orbiter missions and Space Station Freedom utilization.

Spacelab-J represented the first shared Space Shuttle mission between the United States and Japan, and the most ambitious space venture between the two countries to date. It flew aboard Endeavour (STS-47) in September 1992 and addressed forty-four investigations (thirty-five Japanese, nine U.S.) in materials science, fluids research, and biotechnology, as well as research in radiation, cell and developmental biology, neuroscience, human physiology, and technology development. Spacelab-J represented an important step in strengthening international ties between the U.S. and Japan, furthering the cooperative space research program now developing between the two nations in preparation for Space Station Freedom utilization.

The first United States Microgravity Payload (USMP-1) mission was successfully completed aboard Columbia (STS-52) in October 1992. This cargo-bay payload supported the Lambda Point Experiment, a NASA sponsored experiment developed by Stanford University and the Jet Propulsion Laboratory, and the MEPHISTO experiment, the first in a series of joint NASA and French CNES (Centre National d'Etudes Spatiales) sponsored investigations. The Lambda Point Experiment measured the heat capacity of superfluid Helium at the Lambda Point. MEPHISTO (Materials for the Study of Interesting Phenomena of Solidification on Earth and in Orbit) studied the behavior of metals
and semiconductors during their directional solidification from the melt. The NASA developed Space Acceleration Measurement System (SAMS) flew on USMP-1 to provide acceleration data to both investigations.

Currently, the Microgravity Science and Applications Division is preparing for the 1994 flights of the second United States Microgravity Payload (USMP-2) and the second International Microgravity Laboratory (IML-2). Three new U.S. payloads will make their debut on the USMP-2 mission aboard the Space Shuttle Columbia in February 1994. The Advanced Automated Directional Solidification Furnace, developed by the Marshall Space Flight Center, is a multi-zone Bridgman furnace that will be used to develop processes for growing high-quality crystals of electro-optical materials. The Isothermal Dendritic Growth Experiment, developed by the Lewis Research Center and Rensselaer Polytechnic Institute, will support the development of materials science solidification models to predict dendrite growth as functions of material constants and supercooling. This will provide fundamental materials science understanding for Earth-based metal and alloy industrial processing. The Critical Fluid Light Scattering Experiment, developed by the Lewis Research Center and the University of Maryland, will measure the decay rates and correlation lengths of critical density fluctuations in xenon, a nearly ideal model fluid, very near its liquid-vapor critical point. Near the critical point, fluids exhibit many interesting physical characteristics which have been described theoretically in recent years but which are difficult to observe experimentally on Earth. In addition to these new payloads, CNES's MEPHIusto furnace will fly for the second time, and SAMS will fly and record acceleration data to support all the USMP-2 investigations.

The IML-2 mission is scheduled for flight aboard Columbia in July 1994. IML-2 will include seventy-seven investigations supporting over 210 scientists from the U.S. and five international space agencies and fifteen countries. Forty-two microgravity science investigations are planned, including sixteen biotechnology investigations, eleven fluid physics investigations, eleven materials science investigations, and four acceleration measurement/damping investigations. Thirty-five life sciences investigations will be conducted, thirty-two of which are space biology experiments. There will be one human studies investigation and two radiation studies. Experiment development and mission planning are in their advanced stages, and hardware integration is scheduled to begin at the Kennedy Space Center later this year.

The MSAD has recently made several decisions regarding experiments to be flown on the second United States Microgravity Laboratory, currently scheduled for flight on Columbia in mid-1995. The USML-2 payload complement will support fluids, materials science, and biotechnology investigations, as well as several technology demonstrations. The Crystal Growth Furnace, the Drop Physics Module, the Geophysical Fluid Flow Cell, and the Surface Tension Driven Convection Experiment instruments will all fly for the second time on USML-2. The mission will support Protein Crystal Growth and Glovebox investigations. The Mechanics of Granular Materials experiment will fly for the first time on this mission.

NASA is currently exploring the concept of a series of Spacelab missions to Space Station Freedom, referred to as Microgravity Science Laboratory (MSL) missions, to be conducted in 1997 (MSL-1) and 1998 (MSL-2). The intent is to provide microgravity researchers hands-on science opportunities during the time that Freedom is being assembled and outfitted. The Shuttle/Spacelab would be docked to Freedom for periods of 30-45 days, with research conducted both in Spacelab and on Freedom. The MSL series strengthens the concept of "evolution" to Station. Hardware developed for Spacelab will remain fully utilized until Station-unique instruments are available. Additionally, the lessons learned from these longer duration missions will be factored into logistics and operations plans for follow-on Station utilization flights.

Plans for Space Station Freedom

In the mid to late 1990's, the international Space Station Freedom (SSF) will provide additional capabilities to conduct microgravity research, particularly with respect to greater experiment duration and flexibility. Several classes of multiuser microgravity facilities are currently under definition as
candidate payloads for Space Station. These include the Space Station Furnace Facility, the Fluid Physics/Dynamics Facility, and the Modular Combustion Facility, and multi-discipline accommodations to support Advanced Protein Crystal Growth, Biotechnology, and other small payloads.

For each of the major facilities, precursor experiment "modules" have been defined and, in some cases, have been developed and flown. While the top priority for the precursor flights is to meet the investigators' science objectives, these flights will also provide researchers and developers preliminary facility instrumentation and subsystem development opportunities, as well as on-orbit operations experience in advance of Space Station. Facility design will evolve based on experience with precursor experiment hardware designed and operated on the Shuttle "Spacelab" and other carriers.

Each of the classes of instruments currently planned for Space Station Freedom is described briefly below:

The **Space Station Furnace Facility (SSFF)** is being designed to support several materials processing and crystal growth furnaces. While current plans call for deploying the facility in a two double rack configuration, the facility is designed to accommodate multiple double racks of furnace and support system hardware. The Crystal Growth Furnace, which flew on USML-1 and is scheduled for flights on USML-2 and USML-3, is a precursor module for SSFF.

The **Fluid Physics and Dynamics Facility (FP/DF)** will accommodate a wide range of microgravity fluids experiments, including multiphase flow, free surface phenomena, immersed bubble/droplet interactions, and thermophysical property measurements.

The **Modular Combustion Facility (MCF)** will provide containment and diagnostic support for microgravity research of combustion phenomena. This research, significant in terms of its contribution to the combustion science discipline, is also essential to develop and refine fire safety criteria for spacecraft operations. Current concepts for the Fluid Physics/Dynamics Facility and the Modular Combustion Facility address a shared "core" of common support subsystems.

**Advanced Protein Crystal Growth** and **Biotechnology Facility** experiments will likely share a common rack on Space Station Freedom. Accommodations will support multiple protein crystal growth experiment modules. Planned protein crystal growth techniques include vapor diffusion and liquid-liquid diffusion. Advanced concepts for dynamic control of protein crystal growth processes are currently being studied. Precursor modules for the facility currently fly in the Shuttle middeck.

The **Biotechnology Facility (BTF)** experiments are expected to address cell growth, cell fusion, and cell separations research. Current efforts are focused on expanding the ground-based program relative to these research areas and conducting focused flight technology demonstrations in advance of flight experiments.

The **MS AD** will continue to develop **Middeck Class** payloads, payloads of relatively small size and low complexity, during the Freedom era. The emphasis for these small payloads will be on keeping development costs low, flexibility high, and turnaround on experiment results as rapid as possible.

**Opportunities for International Cooperation**

Without question, the need for continued international cooperative efforts is recognized and accepted, as together the United States and its international partners progress towards Space Station Freedom. The cost to support space research is high for all parties involved, whether they be American, European, Japanese, or Canadian. It is essential, therefore, that unnecessary duplication be avoided and utilization opportunities be maximized.

The **International Microgravity Laboratory** mission series and the **Spacelab J** mission represent important milestones in the ongoing efforts to maintain a framework which fosters ongoing dialogue
and plans for future cooperative efforts. Other cooperative activities within the Microgravity Science and Applications Program include a joint Phase A study currently being conducted by NASA and the European Space Agency (ESA) for the Satellite Test of the Equivalence Principal experiment, and the U.S. use of ESA's Glovebox facility on USML-1 and USML-2 in exchange for middeck flights of ESA's Advanced Protein Crystallization Facility. Additionally, NASA has coordinated with its international counterparts in releasing its research announcements, which offer the use of U.S. and international hardware to both U.S. and international investigators.

Several forums exist for identifying and discussing potential opportunities for future cooperative efforts. Foremost among these are the bilateral working groups which exist between the Microgravity Science and Applications Division and its international counterparts in Europe, Japan, and Canada. Opportunities for combined collaborative discussions concerning plans for Space Station are realized through interaction with the International Forum for the Scientific Utilization of Space Station (IFSSUS), which is made up of members from the NASA Space Station Science and Applications Advisory Subcommittee (SSSAAAS), the ESA Space Station Users Panel (SSUP), the Japanese Space Advisory Group (JSAG), and the Canadian Advisory Committee on the Scientific Uses of Space Station (CACSUSS).

Summary

NASA's Microgravity Science and Applications Division is responsible for administering its Microgravity Science and Applications Program. The program utilizes the unique characteristics of the space environment, primarily the near absence of gravity, to expand man's knowledge of the fundamental sciences, materials sciences, and biotechnology, and to demonstrate the feasibility of space production of improved materials that have high technological utility. The potential rewards of the program include a better understanding of the physical processes in our environment, which may lead to refined control strategies, and advancements in technology, which may lead to important commercial applications. NASA has an aggressive space flight program planned for the microgravity science and applications research community, with numerous Shuttle opportunities and a transition to the international Space Station Freedom planned for the 1990's.