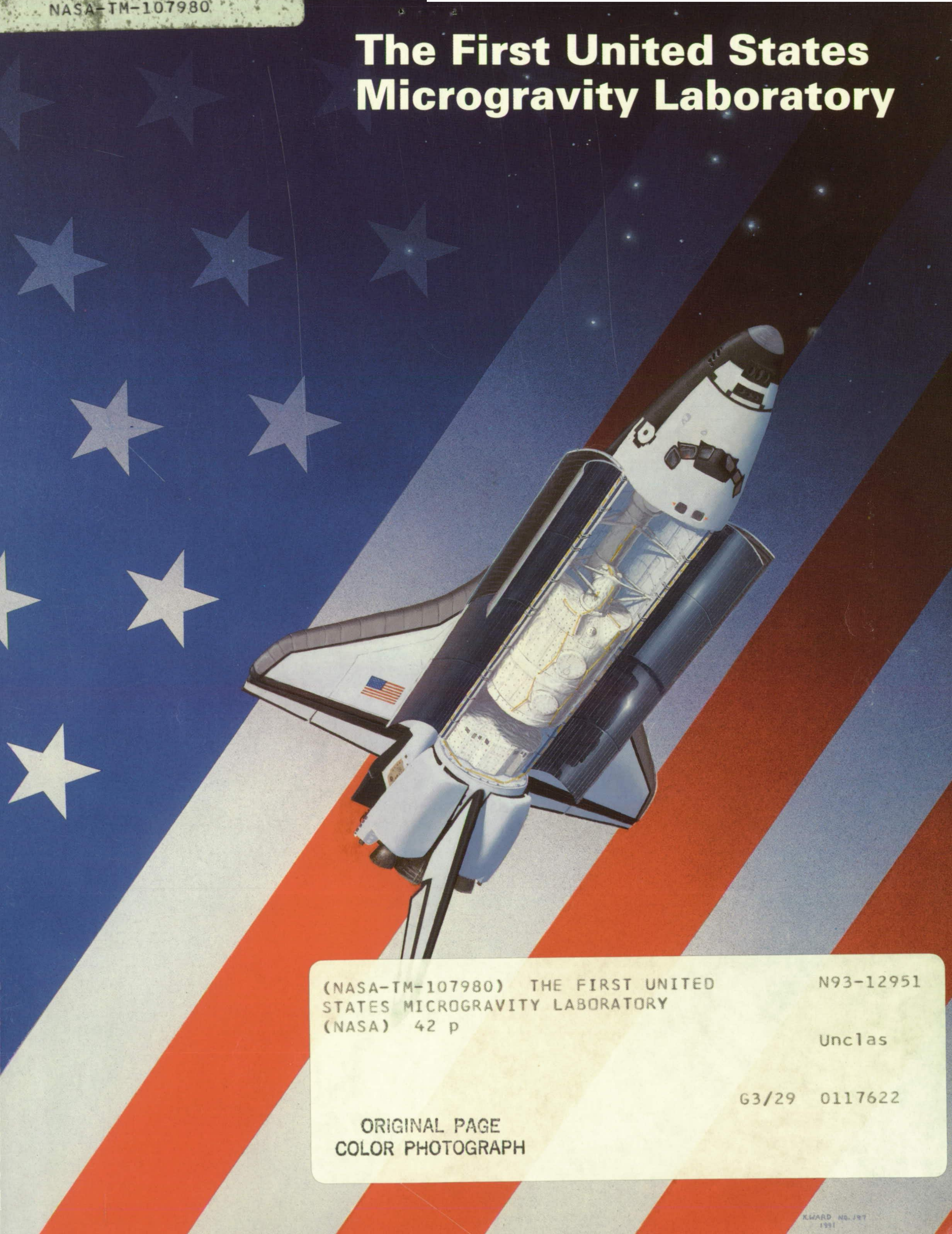
The First United States Microgravity Laboratory



The First United States Microgravity Laboratory

Researching Applications for the Future

NASA
National Aeronautics and
Space Administration

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The United States Microgravity Laboratory Program

An enduring legend in popular science concerns Isaac Newton's discovery of gravity. Myth has it that the theory of gravity was developed after Sir Isaac was hit on the head by an apple while sleeping beneath a tree. However the idea hit him, Newton did theorize that the mass of Earth attracts other masses, from apples to celestial bodies like the Moon. But it took a giant in the field of physics to make this apparently simple connection.

Gravity is so much a part of our lives that we take its influence for granted. Apples fall from trees, milk pours from a jug, and our feet stay firmly on the ground because of gravity. Given the pervasiveness of gravity, it was a brilliant insight to see a falling apple as a body reacting to the pull of a planet.

Newton's discovery began 3 centuries of scientific research and technological development shaped by the recognition of Earth's gravity. Until the mid-20th century, gravity was a largely unavoidable aspect of research and technology. Aircraft, drop towers, and other facilities could provide only extremely short periods of microgravity.

Conducting research that was not influenced by gravity was not possible until rockets that could leave the lower atmosphere were developed. The contents of these rockets experienced extended periods of freefall, or weightlessness, after the rocket motors shut off. These payloads were not truly weightless but were simply falling with the same acceleration as the rocket. This allowed the payloads to float within the rocket as if they had no weight.

The implications of weightlessness, or microgravity, were first seen as technical challenges. When the effects of gravity have been either reduced or eliminated, how do you get the proper amount of fuel to an engine or water to an astronaut? The brief periods of microgravity available in drop towers at the Lewis Research Center and Marshall Space Flight Center were sufficient to answer these basic questions and helped researchers develop pressurized systems and other new technologies needed to cope with the microgravity environment. More time was required, however, to investigate a host of other questions.

The first real opportunity to explore the microgravity environment and conduct research relatively free of the effects of gravity came during the final third of NASA's first great era of discovery. While Mercury and Gemini missions helped answer many technical questions relating to spaceflight, the Apollo missions presented scientists the chance to test ways to use the space environment for research in materials and fluid sciences. Using the microgravity environment for unique research was a focus of the later Apollo flights, and the current NASA microgravity program traces its beginning to these and other experiments conducted on the Apollo-Soyuz Test Project and Skylab, America's first space station.

These early experiments often stimulated new insights into the roles of fluid and heat flows in materials processing. Much of our understanding of the physics underlying semiconductor crystal growth, for example, comes from research initiated with Skylab.

Since the early 1980s, NASA has sent crews and payloads into orbit on a regular basis aboard the Space Shuttle. The Shuttle introduced significant new capabilities for microgravity research: a major increase in payload power, volume, and mass; the return of all instruments, samples, and data; and accommodations for more crewmembers, including scientists. Using the European Space Agency-built Spacelab, a series of pressurized modules and open pallets that can be arranged in different combinations, crews can perform a variety of investigations, many within a laboratory that provides a shirt-sleeve environment.

Microgravity research on the Shuttle began on its third flight, STS-3, in 1982 and continues today on many missions. In fact, most Shuttle missions carry microgravity experiments as secondary payloads. As capable as the Shuttle is, however, reaching its full potential for microgravity research depends on an integrated, coherent program with adequate resources and national support.

From the early missions, NASA learned that more capable instruments and a greater investment in ground-based basic research were needed. Congress has given strong support to this conclusion, and the United States Microgravity Laboratory Program is the first step of a long-term commitment to build a vital microgravity program linking NASA, researchers in fundamental and engineering sciences, and private industry.

The United States Microgravity Laboratory is one part of a science and technology program that will open NASA's next great era of discovery and establish the United States' leadership in space. Built on the pillars of NASA's Space Station Freedom, Mission to Planet Earth, and Mission from Planet Earth, this new era is certain to revolutionize the way we think about space and our world as dramatically as did the Apollo lunar missions.

A key component in the preparation for this new age of exploration, the United States Microgravity Laboratory will fly in orbit for extended periods, providing greater opportunities for research in materials science, fluid dynamics, biotechnology, and combustion science. The scientific data gained on the United States Microgravity Laboratory missions will constitute a landmark in space science, pioneering investigations into the role of gravity in a wide array of important processes and phenomena. In addition, the missions will also provide much of the experience in performing research in space and in the design of instruments needed for Space Station Freedom and the programs to follow in the 21st century.

Coming at the juncture of 2 centuries, the United States Microgravity Laboratory Program is also the connection between 2 great eras in America's space program. They are missions that will help take microgravity research in space from its infancy in the Apollo era to its maturity on Space Station Freedom. ✪

The Fluid State

Everyone has practical experience with fluids—liquids and gases—and we know intuitively how a fluid will behave under "normal" circumstances. Hot air rises, lifting hot air balloons into the sky; water spilled on a tabletop will run over, and even off, the surface; and in any container, whether a glass or a pond, a liquid will seek the lowest possible level. Gravity is ultimately responsible for many of the aspects of fluid behavior we are accustomed to on Earth.

Many of our intuitive expectations do not hold up in microgravity, however, because other forces, such as surface tension, control fluid behavior. While this fact often presents engineers and astronauts with practical problems, space also offers scientists unique opportunities to explore different aspects of the physics of fluids.

The knowledge of fluid behavior gained in space is not only important to basic science but is also the key to new technologies. The behavior of fluids is at the heart of many phenomena in materials processing, biotechnology, and combustion science. Surface tension driven flows, for example, affect semiconductor crystal growth, welding, and the spread of flames on liquids. Drop dynamics is an important aspect of chemical process technologies and in meteorology. Research conducted in microgravity, such as that being conducted on the United States Microgravity Laboratory missions, will increase our understanding of fluid physics and provide a foundation for predicting, controlling, and improving a vast range of technological processes.

The Crystalline State

Everyday experience with materials, both natural and artificial, brings us in contact with a number of different material forms, such as solids and fluids. Just as fluids can be subdivided into liquids and gases, solids can be subdivided into crystalline or non-crystalline (amorphous) forms based on the internal arrangement of their atoms or molecules.

The most common form of solids is crystalline. Examples are minerals, such as quartz crystals or geodes; metals, such as steel, iron, or lead; ceramics, such as a dinner plate or floor tile; and semiconductors, such as the ones in televisions or radios. Crystalline solids have a consistent, three-dimensional order to their internal structure: the atoms line up on planes that are stacked upon each other. Non-crystalline solids, such as plastics, glasses, and wood, have only a local order to their atoms.

Different regions of the crystals typically have the planes lined up in different directions. Crystals with this type of structure are known as polycrystalline materials, and the individual elements are known as grains. The size and orientation of these grains help to determine the strength of metals or the brittleness of a ceramic. Some materials, such as semiconductors, can benefit from the elimination of all grains but one, producing a single crystal with the constituent atoms lining up on a single set of geometric planes.

Crystals can form in many ways: they can result from freezing liquids, the way icecubes form; they can precipitate from solution, the way rock candy is made from a sugar solution; and they can condense from vapor, the way frost forms in your freezer. In all of these cases, gravity affects how the crystals grow. By conducting experiments on crystal growth in microgravity, scientists can learn how gravity influences this process and how crystals grown in microgravity differ from those grown on Earth.

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The First United States Microgravity Laboratory (USML-1)

The first United States Microgravity Laboratory mission (USML-1) launches this important initiative. From investigations designed to gather fundamental knowledge in a variety of areas to demonstrations of new equipment, USML-1 forges the way for future USML missions and helps prepare for advanced microgravity research and processing aboard Space Station Freedom and other platforms. Lasting 13 days, it will be the longest Shuttle flight to date. USML-1 is a cooperative venture between NASA's Office of Space Science and Applications, which manages the mission, and its Office of Commercial Programs.

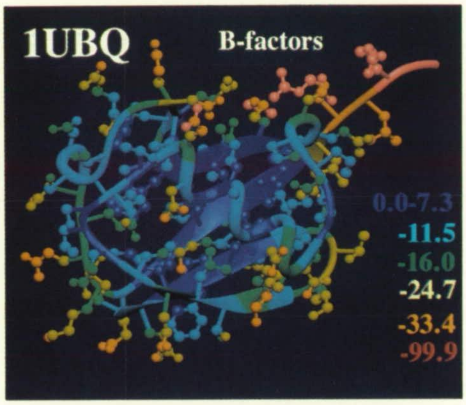
Thirty-one investigations comprise the payload of this first USML mission. The experiments cover five basic areas: fluid dynamics (the study of how liquids and gases respond to the application or absence of differing forces), crystal growth (the production of inorganic and organic crystals), combustion science (the study of the processes and phenomena of burning), biological science (the study of plant and animal life), and technology demonstrations. Experiments will take place around-the-clock to make maximum use of the time in microgravity.

This series of photographs shows a 1-cm diameter drop of silicone oil being deployed using modified nozzle tips during the brief period of microgravity possible on a KC-135 aircraft. Microgravity space research allows scientists to explore hidden areas of drop physics and poses new challenges as well. One such challenge is to create drops of a precise size and volume in the microgravity environment. Experiments on USML-1 will pursue both the scientific and technical challenges of this research.

The fluid dynamics experiments examine basic fluid phenomena, from movement caused by heating to the dynamics of individual liquid drops. Scientists will study several phenomena that are impossible to study on Earth because of gravity's masking effects. A thorough knowledge of both how and why these phenomena occur is needed to understand what influences they have on materials science processes, to develop methods to reduce or eliminate their undesirable effects in Earth-based experiments and processing, and to improve future microgravity research.

Crystals are an integral part of our lives: they help define the basic forms of the proteins that make up our bodies, and they are the basis of the semiconductors that control common home appliances. A crystal's form determines its function. To study both crystals and their uses, scientists need to have crystals that are as perfect as possible. In microgravity, nearly perfect crystals can be grown because the gravity-induced phenomena that cause flaws are reduced or eliminated. The crystal growth experiments on USML-1 will grow a variety of inorganic and organic crystals. The samples will be studied, as well as the methods of producing them. From the data, scientists will learn more about growing crystals in microgravity and about the crystals themselves.

The combustion science experiments examine areas that are normally masked by the effects of Earth's gravity. USML-1 scientists will examine the differences in the shapes of flames and how these spread in microgravity versus gravity. The information gained from these experiments will help scientists better understand the combustion process.



In some cases, larger and more perfect crystals of proteins — the basic building blocks of life — can be grown in the microgravity environment. These crystals, when examined using X-ray diffraction on the ground, can reveal the structure of the protein. Using this information, scientists can develop new or improved drugs. One way this is done is to design a drug that binds to a particular protein. Computer models of the crystalline structure show where the structure is most flexible, the site where the protein will bind to other compounds. In this computer model of the protein Ubiquitin, which binds to other proteins and targets them for breaking down, the color-coded temperature factors (B-factors) of the atoms correspond to the level of flexibility. The interior of the protein is essentially "frozen," while the flexible binding site is the pinkish "tail" in the upper right corner.

The USML-1 biological experiments will explore the production of various products and monitor changes to human physiology as a result of extended exposure to microgravity. These experiments could lead to the development of advanced biomedical implants; a method to help astronauts readjust to normal gravity for landing; and to improved crew health aboard Space Station Freedom.

The technology demonstrations seek to prove experimental concepts and facilities for use on future missions. These demonstrations allow scientists to try new ideas for procedures and facilities at much less cost than full-scale development would require.

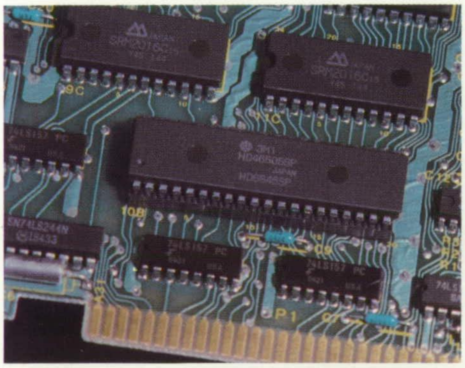
Four new experiment facilities will fly on USML-1. Developed at the recommendation of the Microgravity

Materials Science Assessment Task Force, these facilities are designed for both multiple users and multiple flights.

They are the:

- Crystal Growth Furnace
- Glovebox
- Surface Tension Driven Convection Experiment apparatus
- Drop Physics Module

The Crystal Growth Furnace will house four investigations that will attempt to grow high-quality semiconductor and infrared-detector crystals, using both directional solidification and vapor growth techniques. The Glovebox allows "hands on" manipulation of experiments while isolating the crew from the liquids, gases, or solids involved. On USML-1, it will accommodate 16 technology development and science investigations. The Surface Tension Driven Convection Experiment apparatus will be used to conduct studies of fluid mechanics and heat transfer in low-gravity. The Drop Physics Module will use sound waves (acoustic force) to position and manipulate samples for three investigations into the physical and chemical properties and dynamics of liquid drops.



Inorganic crystals play a large role in our everyday lives. Computers, televisions, remote controls, stereos, microwave ovens, and a host of other products depend on crystals as the basis of the various chips that make them and almost all modern electronics possible. Crystals are at the heart of integrated circuit semiconductors, like those above, that perform calculations and other functions that allow devices to operate. Other crystals act as detectors, and are used in medical diagnostic instruments, security and safety systems, and space-based imaging systems. Research performed in microgravity, such as the four experiments being conducted in the Crystal Growth Facility on USML-1, can teach scientists more about these crystals and the methods used to produce them.

On Earth, gravity plays an important role in the combustion process, from helping to determine the shape of a flame to how that flame spreads over an object. In microgravity, processes masked by gravity may be revealed to investigators. Such studies will not only help with future research but also could have direct applications to a number of terrestrial areas. USML-1 investigations will explore phenomena ranging from a single candle flame, similar to this flame obtained in a drop tower test, to the combustion properties of insulation covering electrical wires.

By trying new ideas and basic designs on small-scale experiments, scientists are able to develop hardware at much less cost than full-scale development would entail. The information on hardware performance gathered during these smaller experiments allows the design of future hardware or facilities to be refined, while providing useful basic science data. USML-1 will test many new pieces of hardware in the Glovebox, such as these developed for the Glovebox Protein Crystal Growth experiment.

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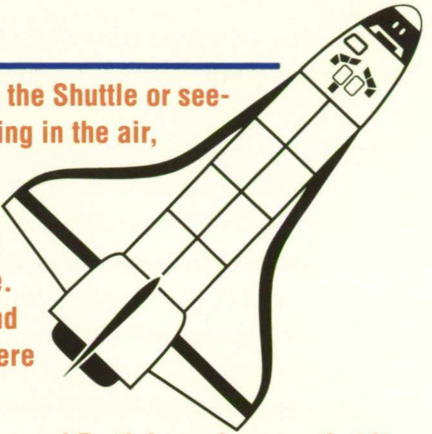
Much of the technology for these facilities builds on experience from previous Shuttle missions, which allowed not only the development of new hardware but also the refinement of the procedures to be used in them. USML-1 will continue this evolutionary process, so America will be assured of having the methods and equipment necessary to lead microgravity research into the next century.

To fully prepare for long-term microgravity research aboard the space station, scientists will require progressively longer times on orbit for their experiments. The USML-1 mission will be the longest Shuttle flight to date, thanks to the Extended Duration Orbiter kit, which enables the Shuttle to prolong the time it remains aloft. The Shuttle Columbia has been modified with extra hydrogen and oxygen tanks for power production, extra middeck locker space, extra nitrogen tanks for the cabin atmosphere, and a regeneration system that will remove carbon dioxide from the cabin air. The Extended Duration Orbiter program could eventually allow the Shuttle to stay on orbit approximately 30 days. ✪

Microgravity In Gravity



When viewing astronauts floating around the Shuttle or seeing a perfectly round drop of liquid spinning in the air, few people realize that these events are taking place in almost Earth-normal gravity. In fact, Earth's gravitational field extends far beyond the Shuttle into space. Given this, what allows the astronauts and contents of the Shuttle to operate as if there were no gravity?

The answer is that the Shuttle is falling around Earth in such a way that it stays the same height above ground. This condition, known as freefall, provides the microgravity environment for the occupants of a spacecraft.

When a Shuttle or any spacecraft going into orbit is launched, it does not fly straight up. Instead, it gradually curves away from a vertical path until it is flying parallel to the ground. It can stay in this path, known as an orbit, without using its engines because of a complex balance of forces. The combination of velocity and direction is referred to in physics as a velocity vector. An orbit is achieved when the velocity vectors affecting a rocket are balanced in such a way that they balance out each other.

Because it has come "up" from Earth, part of the rocket's velocity is directed in a line away from the ground. However, because the rocket did not fly straight up, part of its velocity is directed in a line "ahead" of it. Since it is still within the gravity field of Earth, there is a force pulling the rocket "down." The two velocity vectors, "up" and "ahead," balance out approximately halfway between each other, and if there were no gravity from Earth, the rocket would fly in this path.

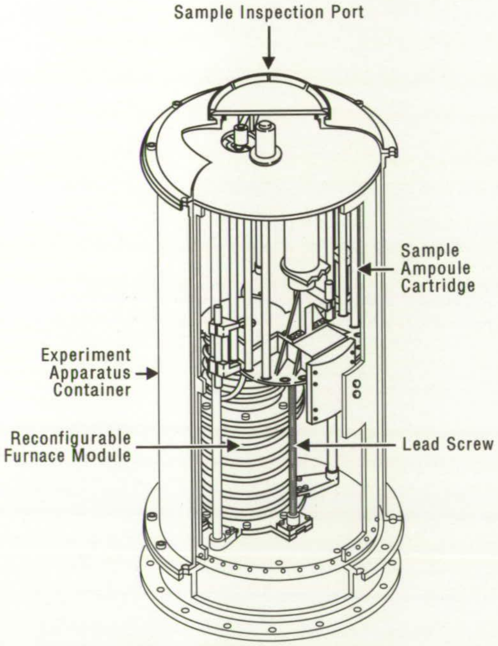
Gravity is pulling "down" on the rocket, causing it to "fall." Rather than coming straight down, the forward velocity of the rocket causes it to fall in a curved path: an orbit. As long as the forward velocity vector remains constant, the rocket will remain in orbit.

Microgravity occurs because the objects in a vehicle in orbit are "falling" at the same velocity as the spacecraft. This is similar to what happens when an elevator drops suddenly; the elevator and the people in it are "falling" together, and for a very brief period of time, the occupants may feel lighter, or even weightless. Unlike an elevator, a spacecraft in orbit provides almost continuous freefall. In a perfect situation, this would result in no gravity. Other forces, however, such as the drag created by the atmosphere and thruster firings, provide minute effects that mimic gravity. These factors produce microgravity, which is approximately one millionth the gravity experienced on Earth.

USML-1 Science

The 31 investigations of the USML-1 mission cover the areas of fluid dynamics, crystal growth, combustion science, biological science, and technology demonstration. The data gathered from these experiments will not only help refine the experiments on the next USML mission but also could have important implications for terrestrial applications.

The experiment descriptions in this section consist of three parts: a statement of *purpose*, the *importance* of the research, and the *method* used to conduct the research. The importance section of each description provides a general introduction to the topic, while the method section provides more specific and detailed information about the experiment. Information is also provided on the new facilities that debut on USML-1. The Crystal Growth Furnace, the Surface Tension Driven Convection Experiment Apparatus, and the Drop Physics Module, along with the investigations to be performed in them, lead the section.



The Crystal Growth Furnace

Crystal Growth Furnace

Pocket calculators, microwave ovens, sensitive heat detectors, computers, portable and home stereos, portable phones, hand-held radios, VCRs, televisions, precise clocks and watches, medical diagnostic instruments, and a host of other products that we use either directly or indirectly everyday have one thing in common: they depend on crystals to operate. From the integrated circuits that control them to the detection elements that sense heat or light, crystals are an integral part of these devices and, therefore, our lives.

Scientists study crystals to learn about the fundamental nature of materials and to develop new applications or improve existing ones. To do this, scientists require crystals as perfect as possible, since the properties of crystals that make them useful are related to the inherent ordering of the atoms and molecules within the crystalline structure. Defects in this ordering can interfere with the properties required for a given application. Gravity contributes to the formation of defects during the production of crystals through convection, sedimentation, and buoyancy effects. These gravity-induced complications result in problems ranging from structural imperfections to chemical inhomogeneity. (Structural imperfections are physical flaws in the internal structure of the crystal. Chemical inhomogeneity is the uneven distribution of the component atoms of the crystal.) Both problems limit the performance of the crystal and, thus, limit the devices in which they are used.

The microgravity environment aboard orbiting spacecraft like the Shuttle and the space station, however, reduces most or all of these complications. By conducting crystal growth research in microgravity, scientists can investigate the different factors affecting crystal growth and determine the best methods to produce various types of crystals.

The Crystal Growth Furnace is a reusable facility for investigating crystal growth on USML missions and is one of the first furnaces ever developed by the U.S. that can process multiple large samples at temperatures above 1,000 °C. The furnace can produce crystals by either directional solidification or vapor crystal growth methods, making it useful to a variety of investigations.

Directional solidification is a method of crystal growth in which solidification proceeds in a particular direction. Three of the Crystal Growth Furnace experiments on USML-1 will be using this method. For these experiments, the Crystal Growth Facility will melt all but one end of the sample, which contains a seed crystal. The furnace will then move, causing the sample to resolidify from the seed. As this occurs, a single crystal is formed.

In vapor crystal growth, or vapor deposition as it is sometimes known, the sample is heated until it begins to vaporize. Then, like steam coming off hot water, the vaporized material flows into a cooler section where it is deposited on the substrate (the "base") for the crystal. A single crystal is formed as additional material is deposited on the substrate and cools. Both methods have advantages for growing certain types of crystals.

The Crystal Growth Furnace can automatically process multiple samples. If needed, however, investigators in Spacelab Mission Operations Control can modify the processing through commands transmitted from the ground to the control computer.

The Crystal Growth Furnace system consists of three major elements: The Integrated Furnace Experiment Assembly, the Avionics Subsystem, and the Environmental Control System. The Integrated Furnace Experiment Assembly includes the Experiment Apparatus Container.

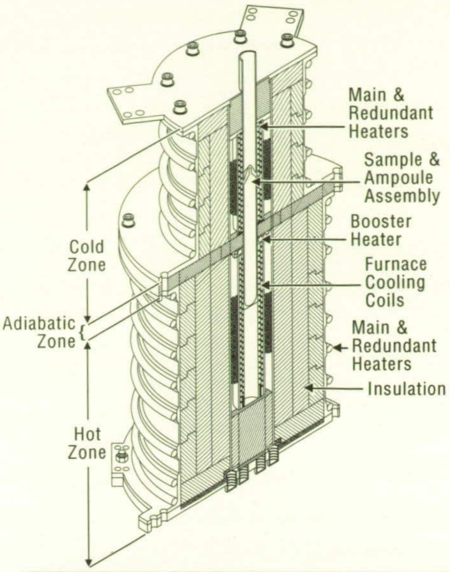
The Integrated Furnace Experiment Assembly is where the Crystal Growth Furnace is mounted. The assembly consists of the Reconfigurable Furnace Module, the Sample Exchange Mechanism, the Furnace Translation System that moves the furnace over the sample being processed, and the Internal Support Structure. The parts of the Integrated Furnace Experiment Assembly are connected to an internal support structure, which provides the support necessary to ensure proper, accurate operations of the furnace.

The heart of the Integrated Furnace Experiment Assembly is the Reconfigurable Furnace Module, which has five controlled heating zones that move over the experiment samples to provide controlled melting (thermal gradient) and optimal crystal growth conditions. Three zones form the hot portion of the module, and two zones form the cold portion. The hot and cold zones are separated by insulation. Moving the furnace over the sample reduces the probability that the crystal will have defects caused by movement-induced accelerations. The module can be modified to provide different heating levels and gradients for use on different missions. This allows the furnace to process a variety of different types of crystals over several missions.

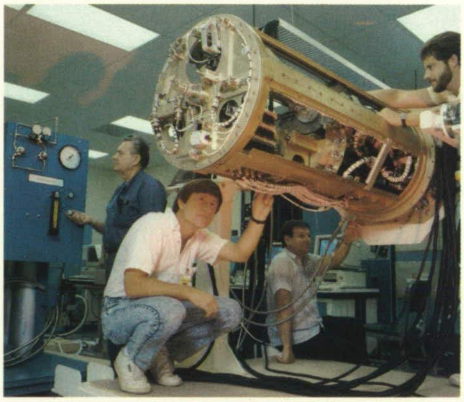
The Furnace Translation System moves the furnace over the sample being processed. It allows precise control of that movement, so optimal growth conditions are obtained.

The Sample Exchange Mechanism makes it possible to process up to six samples automatically. The mechanism consists of a rotary carousel that holds the sample cartridges and will position the appropriate cartridge so that the furnace unit can move over it.

Once on orbit, a crewmember will open the Experiment Apparatus Container, load six experiment samples into the Sample Exchange Mechanism, and close the container. The Environmental Control System controls the atmosphere inside the Integrated Furnace Experiment Assembly and provides cooling to the outer shell of the furnace through connections to Spacelab systems. The samples are processed under computer control, using instructions contained in the flight software. An investigator can transmit new instructions to the computer to change operations if needed. On USML-1, the Crystal Growth Furnace is not scheduled to be opened again until the Shuttle has returned to Earth; however, the crew can gain access through the use of a flexible glovebox if needed. ✪



The Reconfigurable Furnace Module



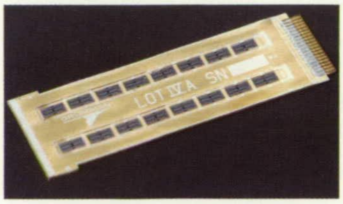
Engineers and technicians work with an engineering model of the Crystal Growth Furnace in preparation for the USML-1 mission.

System Capabilities

• Reconfigurable Furnace Module	
Hot Zone Temperature	**200 to 1,600 °C**
Cold Zone Temperature	**200 to 1,300 °C**
Booster Heater Temperature	**200 to 1,700 °C**
Gradient Zone Length	**0.5 to 7.0 cm**
Control Setpoint Accuracy	**±4 to ±9 °C (dependent on temperature range selected)**
Control Setpoint Stability	**±0.5 °C**
• Furnace Translation Rate	
Directional Solidification	**0.0025 to 8.30 mm/min**
Rapid Translation	**1,200.0 mm/min**
• Processing Atmosphere	**argon**
• Sample Size	
Diameter	**up to 2.0 cm**
Length	**up to 20.0 cm**
• Sample Exchange Mechanism Capacity	**6**

Orbital Processing of High-Quality CdTe Compound Semiconductors

Principal Investigator: Dr. David J. Larson, Jr.
Grumman Corporate Research Center



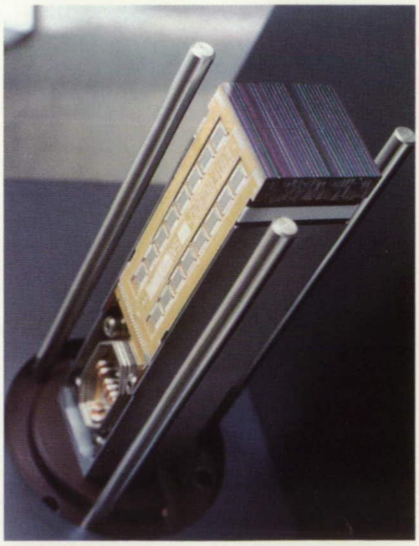
This electronic module is the basic building block of an infrared detector array. The chips running down both sides of the module (up to 32 locations) provide signal processing, while the mercury cadmium telluride infrared detectors are located along the left end of the module. There are 2,048 mercury cadmium telluride detectors located in 8 rows of 256 columns on this edge. The right end of the module connects to the host unit using the module. Experiments on USML-1 could help improve this and other detector systems.

Purpose: This experiment investigates quantitatively the influences of gravitationally dependent phenomena on the growth and quality of alloyed compound semiconductors.

Importance: Cadmium zinc telluride (CdZnTe) crystals are used in a variety of mercury cadmium telluride (HgCdTe) infrared detectors, as lattice-matched substrates. The alloying element, zinc, is used to alter the lattice parameter of the cadmium telluride (CdTe), so there is a perfect lattice match between the substrate and the active HgCdTe detector layer. Lattice matching lowers the generation of defects in the HgCdTe crystal grown on the substrate by minimizing strain where the two layers join. Furthermore, the zinc alloying strengthens the cadmium telluride lattice during growth, reducing the number of native defects in the bulk CdZnTe crystal and the resultant wafers machined from the crystal to be used as substrates. Reducing defects in the substrate minimizes the propagation of defects into the active layer during its growth. Processing the CdZnTe crystals in microgravity could significantly improve the chemical homogeneity of the substrates, thus minimizing interface strain and reducing the defects that result from gravitationally dependent phenomena. This improvement in substrate quality should enhance the quality and performance of the HgCdTe active detector.

Method: The samples on USML-1 will be processed in the Crystal Growth Furnace, using the seeded Bridgman-Stockbarger method of crystal growth. Bridgman-Stockbarger crystal growth is accomplished by establishing isothermal hot-zone and cold-zone temperatures with a uniform temperature gradient between. The thermal gradient spans the melting point of the material (1,095 °C). After sample insertion, the furnace's hot and cold zones are ramped to temperature (1,175 °C and 980 °C, respectively) establishing a thermal gradient of 25 °C/cm between and melting the bulk of the sample. The furnace is then programmed to move farther back on the sample, causing the bulk melt to come into contact with the high-quality seed crystal, thus "seeding" the melt. The seed crystal prescribes the growth orientation of the crystal grown. Having seeded the melt, the furnace translation is reversed and the sample is directionally solidified at a uniform velocity of 1.6 mm/h by moving the furnace and the thermal gradient over the stationary sample.

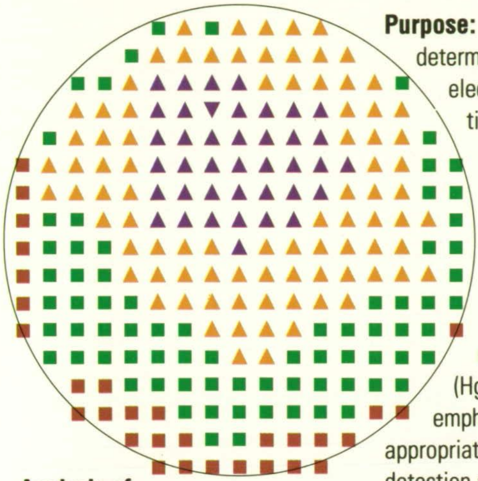
The crystal of CdZnTe will be examined after the mission using infrared and optical microscopy; microchemical analysis; X-ray precision lattice parameter mapping and synchrotron topography; infrared transmission, optical reflectance, photoconductance, and photoluminescence spectroscopy. These characterization techniques will quantitatively map the chemical, physical, mechanical, and electrical properties of the Crystal Growth Furnace flight crystal for comparison with identically processed Crystal Growth Furnace ground-processed samples. These results will be compared quantitatively with the best results accomplished terrestrially using the same growth method. Thermal, compositional, and stress models will be quantitatively compared to the experimental 1-g and microgravity results. ✪



Stacking the detector modules together can provide for larger images, more detailed images, or multiple wavebands. Such systems, like the 30-module bundle shown here, could be useful in Earth imaging.

Crystal Growth of Selected II-VI Semiconducting Alloys by Directional Solidification

Principal Investigator: Dr. Sandor L. Lehoczky
NASA Marshall Space Flight Center



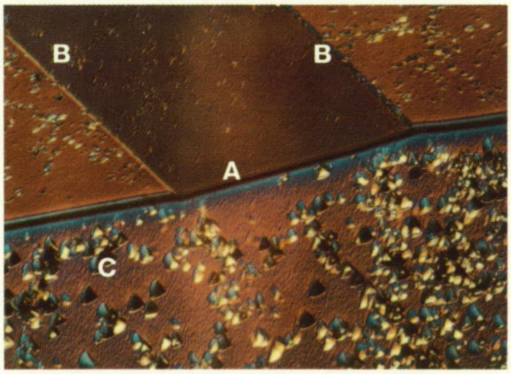
Analysis of an Earth-grown crystal produces this graphical representation that reveals the elements making up the crystal have not mixed together well, a condition known as inhomogeneity. By growing crystals in microgravity on USML-1, a more even mixing of the components should be obtained.

Purpose: This experiment determines how the structural, electrical, and optical properties of selected II-VI semiconducting crystals are affected by growth in a low-gravity environment.

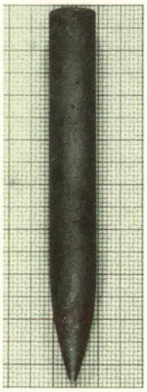
Importance: The alloy being investigated is mercury zinc telluride (HgZnTe), with particular emphasis on compositions appropriate for infrared radiation detection and imaging in the 8- to 12-micrometer (μm) wavelength region. Infrared detection and imaging systems at those wavelengths have the potential for use in applications ranging from resource detection and management on Earth to deep-space imaging systems. HgZnTe crystals are classified as members of the II-VI crystal type because of the position of the constituent atoms in the vertical columns of the periodic table.

This experiment has three major goals: to evaluate the effect of gravitationally driven fluid flows on crystal composition and microstructure, to determine the potential role of irregular fluid flows and hydrostatic pressure effects in causing crystal defects, and to produce a sufficient quantity of high-quality crystals, so scientists can perform bulk crystal property characterizations and fabricate detectors to establish ultimate material performance limits. On Earth, gravity-induced fluid flows and compositional segregation make it nearly impossible to produce homogenous, high-quality bulk crystals of the alloy.

Method: The samples will be processed in the Crystal Growth Furnace using the directional solidification crystal growth method. The liquidus temperature of mercury zinc telluride is 695 °C for the selected composition. The hot zone of the furnace will be 800 °C for melting, and the cold zone will be 350 °C. A portion of the sample will be melted in the hot zone, and crystal growth will occur in the resulting temperature gradient. The furnace and, thus, the temperature gradient, will be moved slowly across the sample at a rate of approximately 3.5 mm per day. The slow rate is required to prevent constitutional supercooling ahead of the solidification interface. This rate is the maximum theoretical growth speed allowed by the constitutional supercooling criteria relating to interface breakdown. The samples produced on USML-1 will be examined after the mission for chemical homogeneity and microstructural perfection by using a wide array of characterization techniques, including optical and electron microscopy, X-ray diffraction, X-ray topography and X-ray energy dispersion, infrared transmission spectroscopy, and galvanomagnetic measurements as a function of temperature and magnetic field. Selected slices from the crystal will be used to fabricate device structures (detectors) for further evaluation. ✪



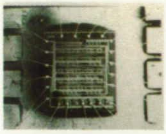
This color electron photomicrograph shows such common structural defects as a grain boundary (A), twin boundaries (B), and triangular-shaped dislocation etch pits (C). These defects were revealed by chemical etching of a wafer cut from a crystal of a II-VI semiconducting alloy, which was produced by directional solidification.



A typical ground-grown mercury zinc telluride alloy crystal

The Study of Dopant Segregation Behavior During the Growth of GaAs in Microgravity

Principal Investigator: Dr. David Matthiesen
GTE Laboratories



This computer chip is made with gallium arsenide. Because of its variety of electronic properties, many people believe that gallium arsenide may one day replace silicon as the most popular material for building semiconductors. Experimentation on USML-1 will allow scientists to better understand this important substance and its potential.

Purpose: This experiment investigates techniques for obtaining complete axial and radial dopant uniformity during crystal growth of selenium-doped gallium arsenide (GaAs).

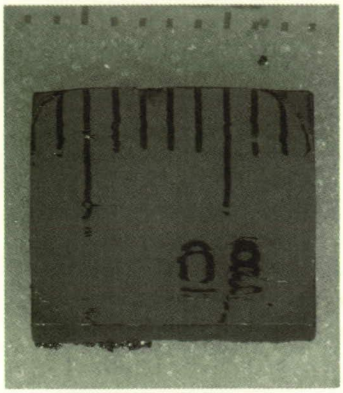
Importance: Gallium arsenide is a technologically important semiconductor used in a variety of applications, such as high-speed digital integrated circuits, optoelectronic integrated circuits, and solid-state lasers. Typically, semiconductors have a very small amount of impurity added to them to precisely engineer their material properties. These impurities, called dopants, are usually added at a level of 10 parts per million. This means, in this experiment, that for every million semiconductor atoms in the crystal, 10 atoms of dopant are added. Because of convection in the melt on Earth, it is very difficult to precisely control where these dopant atoms end up in the crystal. Too many in one part versus another, a condition known as inhomogeneity, leads to widely varying material properties throughout the crystal. This experiment will use GaAs doped with selenium to investigate the potential of the unique microgravity environment to achieve uniform dispersal of the dopant during crystal growth.

Method: Only one experiment sample will be processed on USML-1 because of time constraints. This sample has been uniquely designed to eliminate other forms of convection, such as surface tension driven convection. The hot zone (1,255 °C) and the cold zone (1,225 °C) temperatures are chosen to locate the 1,238 °C melting point of GaAs in the center of the gradient zone. After the mission, scientists will use an extensive array of characterization techniques to analyze this material. This will include electrical measurements by Hall effect and capacitance-voltage techniques, chemical measurements by glow discharge mass spectroscopy, and optical measurements by advanced quantitative infrared microscopy and Fourier transform infrared spectroscopy. These data will be compared to current analytical and computer model based theories of crystal growth.

An Earth-grown gallium arsenide crystal seen next to a pencil for comparison

Vapor Transport Crystal Growth of Mercury Cadmium Telluride in Microgravity

Principal Investigator: Dr. Heribert Wiedemeier
Rensselaer Polytechnic Institute

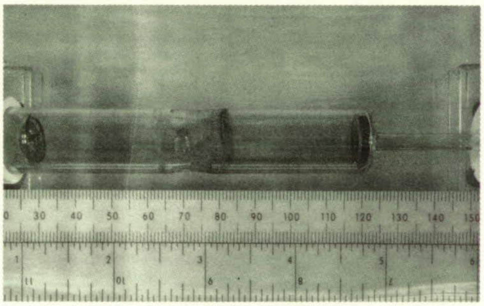


This photograph shows an epilayer of mercury cadmium telluride grown on a cadmium telluride substrate during a ground-based experiment before USML-1. The ruler markings are refracted images from the ruler placed beside the crystal.

Purpose: This experiment establishes the relationship between convective flow, mass flux, and crystal morphology and identifies the effects of microgravity on crystal properties of $Hg_{0.8}Cd_{0.2}Te$.

Importance: Mercury cadmium telluride crystals are very effective in infrared detectors used for a variety of purposes, such as defense, space, medical, and industrial systems. Crystals free of large structural defects and with a more even dispersion of the constituent elements will improve detector performance. To better understand the factors that influence HgCdTe crystal growth, this experiment will examine phenomena ranging from temperature profiles to how the aspect ratio (shape) of the sample ampoule affects mass transport and crystal growth.

Method: The samples will be processed in the Crystal Growth Furnace using vapor transport crystal growth techniques, which do not require temperatures as high as the directional solidification process used on other samples. For this experiment, the hot zone of the furnace will be 590 °C, and the cold zone will be 540 °C for deposition. This temperature gradient will be held steady over the sample. After the mission, the crystals produced will be examined using X-ray diffraction, optical microscopy, scanning electron microscope/wavelength dispersive spectroscopy, chemical etching, Hall measurement and other techniques for evaluation of morphology, structural perfection and properties of the crystals. The crystals produced may be used to fabricate an infrared detector for further examination of their device performance. ✪



A vapor transport crystal growth sample/ampoule assembly for use on USML-1

Surface Tension Driven Convection Experiment (STDCE) Apparatus

Most high-tech crystals, metals, and alloys are produced from liquids or gases that are heated and then solidified. Unfortunately, unwanted flows in the liquids and gases often cause defects that keep these materials from reaching their potential as computer chips, turbine engine blades, and other advanced products. On Earth, buoyancy-driven flows and convection impede attempts to grow better crystals and solidify new metals and alloys. In space, these flows are eliminated, but other fluid movements that are overshadowed on Earth take on new importance.

Ground-based and preliminary space experiments have shown that thermocapillary flows—fluid motions generated by temperature variations along the free surfaces of liquids—can be an important factor in the low-gravity environment. These flows are of inherent scientific interest and can also occur in many industrial and materials processing techniques.

This streak photograph shows the steady-state flow pattern produced in 1-g with laboratory hardware. The thermal stratification of the flow can clearly be seen.

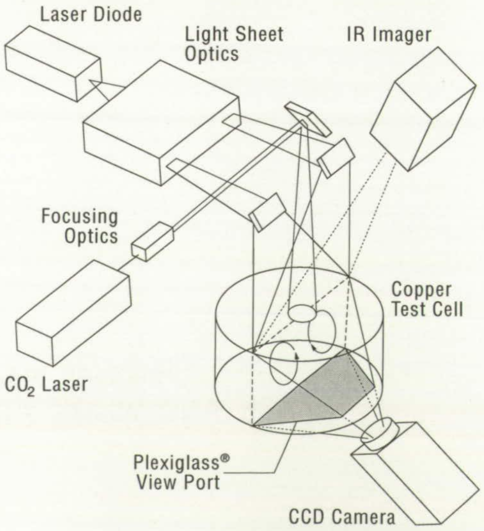
Investigators have attempted to model these flows; however, they lack critical data because the flows are so difficult to detect in Earth-based experiments where buoyancy-driven flows dominate. In low-gravity, buoyancy-driven flows are minimized, and other flows, such as thermocapillary flows, become dominant. Also, in low- gravity, the shape of the liquid's free surface and the way the surface responds to imposed flows and forces (e.g. impulses) are different. These conditions cannot be simulated in Earth-based experiments, since the gravity effect is dominant and keeps the surface of a liquid flat. In space, investigators will be able to examine how various controllable factors, such as different imposed surface temperature distributions (thermal signatures) and interface shapes, influence thermocapillary flows.

This apparatus consists of the experiment package and an electronics package located in a double Spacelab rack. The experiment package includes the test chamber, made of copper to assure good thermal conductivity along the walls, and the silicone oil system consisting of a storage reservoir and a fluid management system for filling and emptying the test chamber. A lightweight (10 cSt) silicone oil is used because it is not susceptible to surface contamination, which can ruin surface tension experiments.

Two heating systems, which constitute the different thermal signatures, are part of the test chamber. A submerged heater system will be used to study thermocapillary flows over a range of imposed temperature differences. A surface heating system will be used to investigate fluid flows generated by various heat fluxes distributed across the surface of the liquid; this heating system consists of a CO_2 laser and various optical elements that direct the laser beam to the test chamber and vary the imposed heat flux and its distribution. Analysis of the flows resulting from the diverse imposed thermal signatures will provide options for properly tailoring the fluxes.

To visualize the flows, a laser diode and associated optical elements will illuminate aluminum oxide particles suspended in the silicone oil, and a video camera attached to a chamber viewport will record the particle motion. An infrared imaging system records oil surface temperature. The crew can use a Spacelab camera mounted to the front of the chamber to monitor oil filling and draining, submerged heater positions, and oil surface shapes and motions. ✪

A schematic view of the test cell and associated hardware shows how the CCD camera images light scattered from aluminum oxide particles in the silicone oil when the oil is illuminated by the laser diode light sheet. The CO_2 laser imposes a Gaussian-shaped heat flux on the surface of the oil while theinfrared imager detects thermal energy radiated from the free surface, thus providing a two-dimensional surface temperature map.



System Capabilities

- **Sample Summary**

Sample liquid:	**10 cSt silicone oil**
Volume:	**400 ml with adequate concentration of tracer particles**
Initial temperature:	**25 °C**

- **Instrument Equipment**

Test chamber dimensions:	**5 cm high x 10 cm diameter**
Video camera	
Infrared imager:	**8 to 12 microns, scanning type**
Thermistors	

- **Heating Parameters**

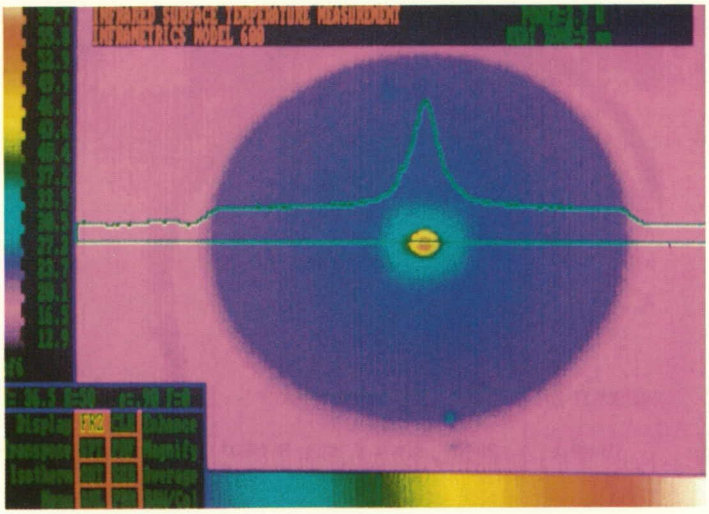
Constant flux heating CO_2 laser heating; zone: 5 to 30 mm, flat & curved surfaces:
0.5 W (60 min, thermal equilibrium)
0.2 to 3.0 W (10 min, velocity equilibrium)

Constant temperature heating cartridge heating, flat & curved surfaces:
1.5 W (60 min, thermal equilibrium)
1.0 to 17.0 W (10 min, velocity equilibrium)

Temperature differences **10 to 65 °C**

Surface Tension Driven Convection Experiment

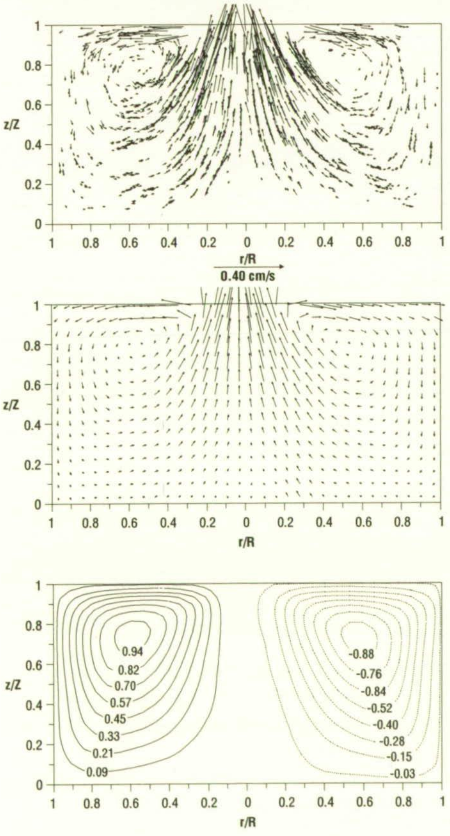
Principal Investigator: Dr. Simon Ostrach
Case Western Reserve University



This thermogram, or two-dimensional surface temperature map, was created by an infrared imager during a ground test. The outer edge of the blue circle is the boundary of the test cell. The surface temperature of the liquid is indicated by the scale on the left.

Purpose: This investigation studies the basic fluid mechanics and heat transfer of thermocapillary flows in low-gravity.

Importance: Variations in surface tension, caused by temperature differences along a liquid's free surface, generate thermocapillary fluid flows. Although such flows exist on Earth, buoyancy-driven flows are usually stronger, making it difficult to observe thermocapillary flows. In low-gravity, buoyancy-driven flows are reduced, making it easier to examine thermocapillary flows. In addition, the shape of the liquid's free surface and the damping characteristics will be different in space; therefore, these flows are impossible to simulate on Earth. The USML-1 Surface Tension Driven Convection Experiment is the first to use state-of-the-art instruments to obtain quantitative data on thermocapillary flows over a wide range of parameters in experiments that vary the thermal signatures and the configuration of the liquid's free surface. Under certain conditions, the flows will oscillate, and scientists will examine what conditions cause these oscillations. These data will help scientists understand the oscillations and provide a database for developing numerical models that are used to predict thermocapillary flows. This information has practical applications, because thermocapillary flows can disturb the production of materials, such as molten glass produced by containerless processing, and affect fluids in spacecraft life- and flight-support systems, such as water purification systems and fuel management and storage systems.



These three diagrams show processed flow visualization data from a ground-based test. The data are processed using an electronic Particle Image Velocimetry system. (A) shows the raw velocity vectors, while (B) shows that data interpolated on a regular grid, and (C) shows the stream function calculated from the interpolated data. Because the data were acquired very early during the test, the flow is not yet thermally stratified. The distortion caused by viewing from the bottom of the test cell is corrected during data reduction.

Method: For USML-1, both steady flows (those that do not change over time) and transient flows (those that do change over time) will be studied. A variety of conditions and experiment configurations will be used, and an attempt will be made to identify the conditions for the onset of oscillations.

In the first series of experiments, a cylindrical container (10 cm in diameter and 5 cm high) will be filled with silicone oil. Two heater systems will be used to heat the free surface to various temperatures to generate thermocapillary flows. A centrally located submerged heater will impose a constant temperature difference between the heater and container walls, and a CO_2 laser will impose a heat flux on the liquid surface to produce various temperature distributions along the liquid's surface. For both heater systems, the container will be filled to different oil levels to create both flat and curved surfaces. Investigators will obtain detailed data on flow velocity, temperature fields, and surface temperatures induced by the two different thermal signatures at various thermal differences, heat flux levels and distributions, and free surface shapes. Using this information, they will define the nature and extent of thermocapillary flows in low-gravity.

The container will be connected to a sophisticated data acquisition system that provides temperature and flow field measurements. A laser-light sheet, reflected by aluminum oxide particles mixed with the oil, will allow observation of fluid flows. A video camera attached to a viewport below the test chamber records the fluid flows. A scanning infrared imager will measure oil surface temperature, an important measurement because it determines the driving force of the flow. Thermistors inside the test chamber will measure bulk oil temperatures. These data will be downlinked to the Spacelab Mission Operations Control Center at the Marshall Space Flight Center. Investigators at the Spacelab Mission Operations Control Center will reduce and analyze the data. Based on the analysis of the data, a new set of test parameters for the next series of experiments will be uplinked to the experiment computer in the Spacelab. From the data obtained, scientists can correlate velocity and temperature distributions with imposed thermal conditions to complete mathematical models of thermocapillary flow. Research to date indicates that these flows are caused by a complex three-way interaction among the driving force, the fluid flow, and the surface shape. ✪

Drop Physics Module

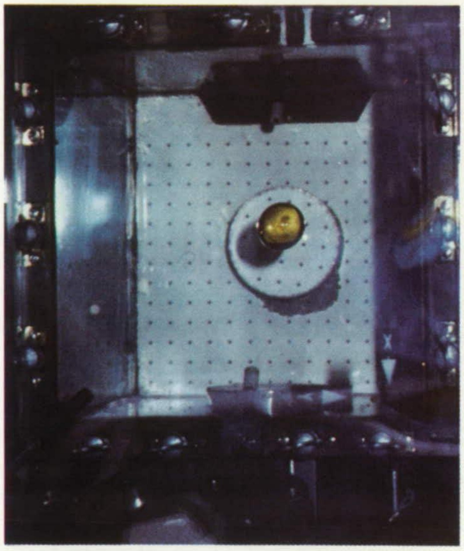
The Drop Physics Module gives scientists the opportunity to test theories of classical fluid physics. These long-standing theories have not been confirmed by experiments conducted on Earth because, to overcome the force of gravity, very strong sound waves have to be used to levitate even tiny drops. These strong sound waves introduce forces that distort the shape of the drops and mask the subtle phenomena being studied. In microgravity, relatively weak sound waves, such as the ones being used in the Drop Physics Module, can be used to suspend and manipulate drops and even solid materials.

By studying free drops (drops of material untouched by any solid surface) suspended in microgravity, scientists have the opportunity to test basic fluid physics theories that have applications in other fields of physics. For example, by studying how one drop splits into two drops, scientists can learn more about the process of nuclear fission, the splitting apart of atoms. The insights gained from studies in the Drop Physics Module can be applied to phenomena ranging from the splitting of atoms in nuclear reactors to distant, massive rotating stars.

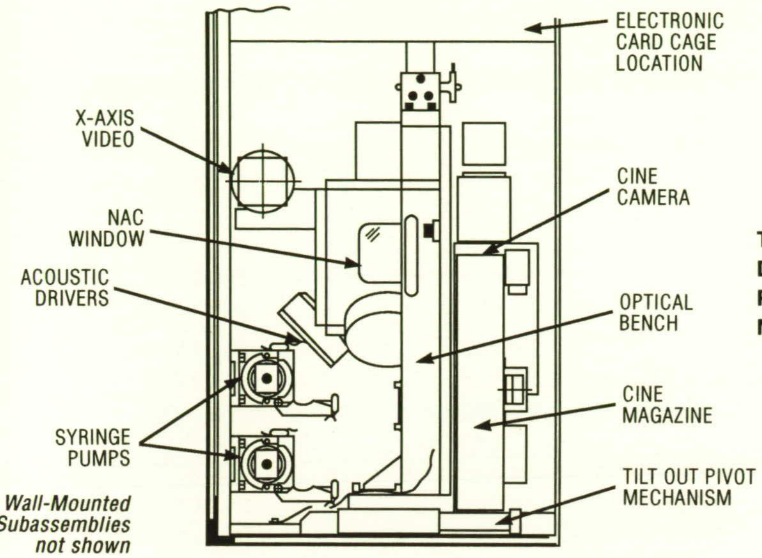
The Drop Physics Module is dedicated to the detailed study of the dynamics of drops in microgravity: their equilibrium shapes, the dynamics of their flows, and their stable and chaotic behavior. It also demonstrates a potentially valuable processing technique known as containerless processing. The Drop Physics Module and microgravity combine to remove the effects of the container, such as chemical contamination and shape, on the sample being studied. Sound waves, generating acoustic forces, are used to hold a sample away from the walls of the experiment chamber, which isolates the sample from potentially harmful external influences. On future missions, a high-temperature positioner, using either acoustic, electromagnetic, or electrostatic forces for positioning, can be installed in the second Drop Physics Module experiment bay to melt samples that are solids at room temperature, so they can be studied as fluids at high temperatures and then resolidified. All of this can be done without any physical contact with the sample.

A crewmember conducts an experiment by directly selecting commands from menus displayed on one of two video displays or by selecting an experiment identification label and executing a sequence of preprogrammed commands. The operator can monitor the response of the drop on a second adjacent video display, choosing one of two views of the drop. All selections are made through a novel integrated video menu display/infrared touch grid.

Liquid samples deployed into the rectangular experiment chamber are positioned by the sound waves so that film and video cameras can record the liquid's behavior. Small particles have been mixed with most of the fluids to make the fluid motion inside the drop



A liquid drop is manipulated in the Drop Dynamics Module on Spacelab 3. The scientific and engineering data collected in this and other experiments resulted in the development of the more advanced Drop Physics Module for the USML missions.



The Drop Physics Module

visible. During an experiment, a crewmember can modulate the sound wave to rotate, oscillate, or move the sample inside the chamber. After each experiment, the fluid will be retrieved and, if necessary, the interior of the chamber cleaned.

A variety of fluids have been selected to fly on USML-1. Very pure water, water with tiny amounts of contaminants (surface-active materials), water with various amounts of glycerin to make it more viscous, like molten glasses, and silicone oils are some of these fluids. Some will be used in pairs to form drops within other drops.

Scientists on the ground can sometimes observe real-time video from the module. This will allow them to discuss the experiment with the operator, do quick analysis of the images and make suggestions to the operator to maximize the scientific return. ✪

System Capabilities

- **Sample Summary**

Samples	**Liquid drops, liquid shells, solid samples (For USML-1, only liquid drops will be used.)**
Diameter	**0.5 to 2.7 cm drops**
Temperature Range	**Ambient**

- **Acoustic Drive**

Carrier Frequencies	**1 to 8 kHz**
Force Modulation	**1 to 30 Hz**
Sound Pressure Level	**130 to 155 dB**
Torque	**0 to 1.0 dyne/cm (maximum)**

- **Instrumentation**

Video Imaging	**30 frames/sec with 1/60 to 1/1,000 sec shuttering** **resolution: 120 μm with 4.7-mm field of view**
Cinefilm Imaging	**16-mm monochrome or color** **variable frame rate: 10 to 400 frames/sec**
Thermocouples	**±1 °C accuracy**

Hydrostatic pressure, humidity, and temperature sensors

Laser-sheet lighting illumination

Cathode-ray tube and system parameter displays

Process Control and Data Acquisition microprocessor

Drop Dynamics Experiment

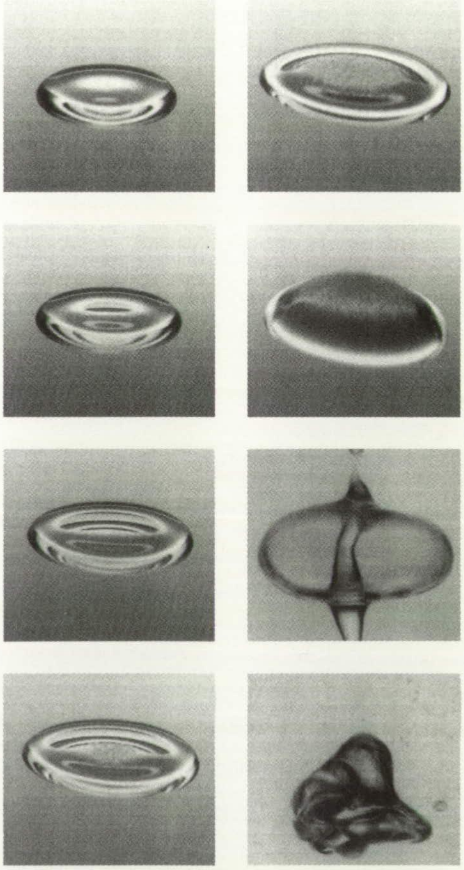
Principle Investigator: Dr. Taylor Wang
Vanderbilt University

Purpose: This experiment gathers data on the behavior of drops and shells in low-gravity to compare with theoretical predictions and to provide insight for the development of new fields, such as containerless materials processing in space.

Importance: Preliminary experiments using acoustic levitation to suspend drops were first completed in the Drop Dynamics Module flown on the Spacelab 3 mission in 1985. These experiments not only confirmed some theories about drop behavior but also provided unexpected results. For example, the bifurcation point, when a spinning drop takes a dog-bone shape to hold itself together, came earlier than predicted under certain circumstances. This experiment, conducted in the more advanced Drop Physics Module, gives investigators a chance to resolve the differences between experiment and theory. Investigators will also study large-amplitude oscillations in drop shape and the process of drop fission.

Ground-based research conducted after Spacelab 3 revealed another important effect: the centering mechanism of an oscillating compound drop. Studied experimentally for the first time on USML-1, this not only has fundamental scientific interest but, more importantly, can contribute to a new field of research that uses cell transplantation to cure hormone deficiency states in humans, such as diabetes. This treatment would encapsulate living cells with a semi-permeable membrane to protect them from a hostile environment. Experimentation on USML-1 will contribute to understanding how to keep the living cells at the center of such a drop (encapsulation) and away from harmful chemicals during the formation process.

Studies on USML-1 could lead to the development of an optimal method of centering living cells for encapsulation. Properly centered cells, such as this islet cell, may prove to be of medical benefit.



As part of the Drop Dynamics Experiment, water drops will be "squeezed" by intense acoustic fields. By studying the dynamic behavior of drops as they are gradually flattened and destroyed, as seen in this sequence of an Earth-based experiment, scientists can learn about drop stability and the dynamic behavior of drop shapes as a function of acoustic force.

Method: Film (cine) and video records will be made of the experiment for analysis on the ground. These data will allow the equilibrium shapes and frequency spectrum of both simple and compound liquid drops, undergoing different types of rotation and oscillation, to be determined.

To determine the equilibrium shapes of rotating drops, the relative phase between the orthogonal acoustic waves used to position each drop will be shifted by 90 degrees. This phase shift will create an acoustic rotational torque on the drop. The procedure will be done with drops of water, water and glycerin, and silicone oil.

To determine the shape oscillation frequency of both simple and compound drops, the acoustic field will undergo carrier modulation to stimulate drop shape oscillation. The amplitude of the oscillation as a function of the modulation frequency will be studied to determine the non-linear behavior of the drop.

The encapsulation study will use sodium alginate and calcium chloride to study methods for centering one component of a compound drop. In this experiment, sodium alginate droplets will be injected into a calcium chloride drop. The resulting compound drop will be subjected to various acoustic conditions to try to determine an optimal method of forming uniform concentric spherical membranes.

ORIGINAL PAGE
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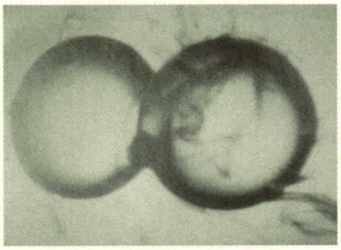
Science and Technology of Surface Controlled Phenomena

Principle Investigator: Dr. Robert E. Apfel
Yale University

A 2.5-mm diameter water droplet undergoes quadrupole shape oscillations.



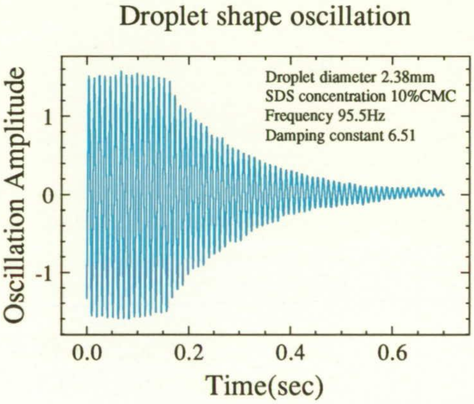
This photograph shows two surfacant-coated hexane drops starting to combine (coalesce). This portion of the process of combining is known as the inception of coalescence.

Purpose: This experiment determines the surface properties of liquid drops in the presence of surfactants (materials that migrate toward free surfaces or toward the interface between two liquids) and investigates the coalescence of droplets with surfactants, using a variety of techniques that disturb the interface between drops.

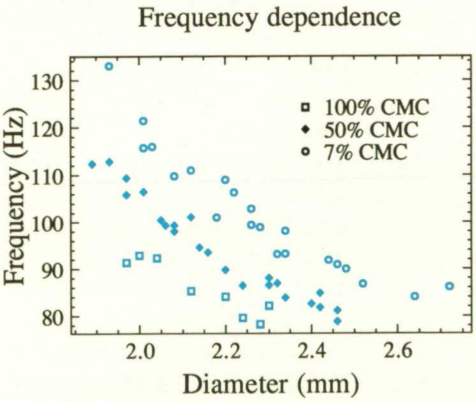
Importance: Surfactants play an important role in countless industrial processes, from the production of cosmetics to the dissolution of proteins in synthetic drug production to enhanced oil recovery. This set of USML-1 experiments, coupled with the current theoretical work of the science team, should give a better understanding of the molecular-level forces acting in the surface layer of simple water drops and provide a better basis for industrial applications than earlier empirical results. In microgravity, where drops can be studied through containerless techniques, levitated drops have well-characterized surfaces, and interfacial forces dominate gravitational forces. Through experiments that cause single, spherical drops to oscillate and change shape, scientists will observe the decay of the oscillations, allowing them to measure surface viscosities and elasticities of the drops. The dual-drop coalescence experiment will give scientists insight into the role of surfactants as "barriers" to coalescence, perhaps allowing them to determine optimal methods for overcoming barriers that keep drops from combining.

Method: In the first set of experiments, single water drops containing varying concentrations of surfactants will be positioned stably by the acoustic field of the Drop Physics Module. The drop will be squeezed acoustically and then released, exciting it so that it oscillates in a quadrupole shape. The frequency and damping of the resulting free oscillations will be measured. These results will be analyzed with the help of theoretical expressions that relate the measured quantities to surface properties (for example, shear and dilatational viscosities). The process will be repeated both for varying surfactant concentrations and for different surfactants.

In the second group of experiments, two water drops containing varying concentrations of surfactants will first be positioned stably at separate nodes of the Drop Physics Module acoustic field. They will then be brought slowly into contact by carefully mixing acoustic modes to force the drops toward each other. If the drops do not coalesce spontaneously (which will be the case as surfactant concentrations increase), a combination of static squeezing and then forced oscillation will be applied to the contacting drops with increasing strength, inducing them to combine. Both the parameters of the induction techniques and the interface between the drops will be measured during this process in an attempt to characterize critical parameters that force the drops to rupture and coalesce. These experiments will be repeated for varying drop sizes and surfactant concentrations. ✪



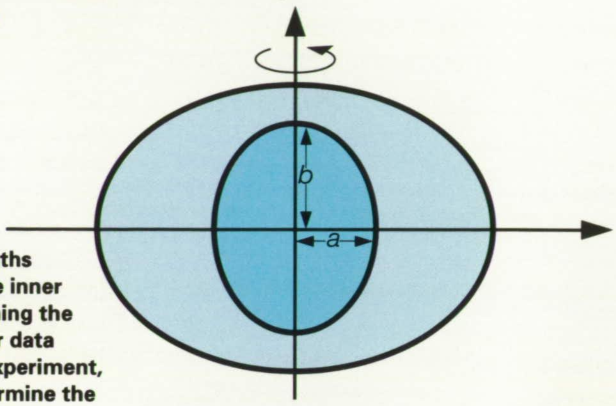
This graph shows the time history of the damped quadrupole shape oscillations of a water droplet that has a small concentration of surfactant.



This graph shows the quadrupole resonance frequency of water droplets as a function of droplet diameter and surfactant concentration.

Measurement of Liquid-Liquid Interfacial Tension and the Role of Gravity in Phase Separation Kinetics of Fluid Glass Melts

Principal Investigator: Dr. Michael C. Weinberg
University of Arizona



By measuring the lengths of the semi-axes of the inner drop (a, b) and combining the information with other data gathered during the experiment, investigators can determine the interfacial tension of the drop.

Purpose: This experiment assesses how gravity affects phase separation kinetics and the geometrical structure of a two-phase glass and explores a unique method for measuring an important surface parameter—the tension between interfaces of drops and other materials.

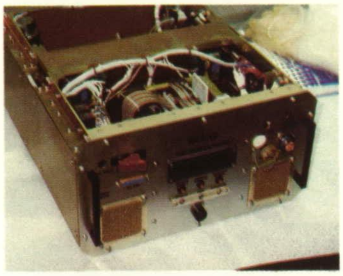
Importance: There are many liquid solutions that tend to separate into several liquid phases when held in an appropriate temperature range. This same process occurs in many glass systems, where it is referred to as glass-in-glass or liquid-liquid phase separation, or amorphous immiscibility. In both liquids and glasses, the rates at which these phase separation processes occur depend upon several factors, such as the temperature and the characteristics of the surface at the boundary between phases. The measurement of the liquid-liquid interfacial tension will provide one of the key quantities that governs the rate of such a process. This experiment will use the spinning drop measurement technique in the Drop Physics Module to measure the interfacial tension and to validate the use of this method in the microgravity environment. If successful, it could be used to measure the interfacial tension in high-temperature glasses, something that cannot be done on Earth.

Method: This experiment will measure the liquid-liquid surface tension of a compound drop consisting of two liquids that do not mix. This compound drop will be rotated in the Drop Physics Module at specified angular velocities, and the shapes of both the inner and outer drops will be distorted. Photographs will provide a precise record of both drops' new geometries. Scientists will analyze the photographs to determine the drop distortions and will use theoretical models to calculate the liquid-liquid surface tension between the substances that make up each drop. Measurements will be made of several drop pairs with different properties and surface interactions. ✪

The remainder of the USML-1 investigations are conducted in smaller individual new facilities or in previously developed and flown hardware. These investigations are listed alphabetically for ease of reference. The science section concludes with a description of the new Glovebox and the experiments to be performed in it.

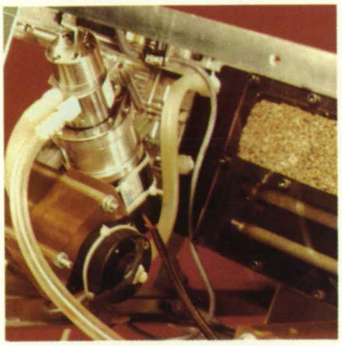
Astroculture™

Principal Investigator: Dr. Theodore W. Tibbitts
Wisconsin Center for Space Automation and Robotics, University of Wisconsin



The Astroculture™ flight unit

As part of the preparation for USML-1, crops were raised in the engineering model of the Astroculture™ unit.



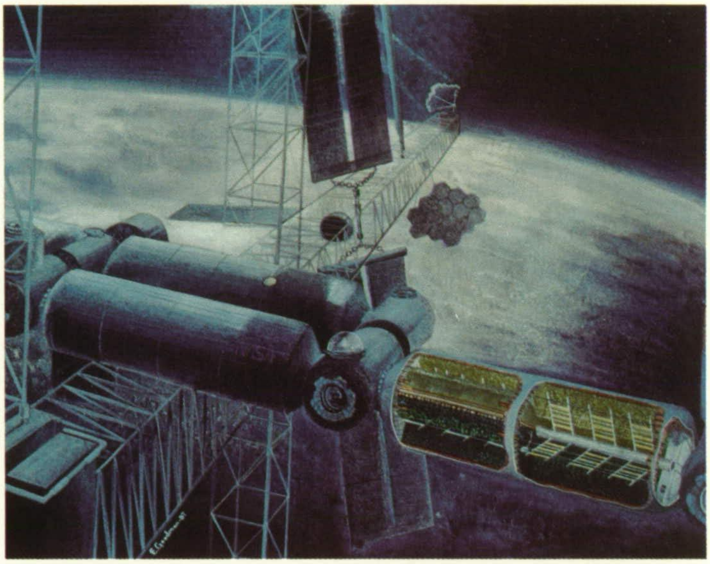
The Astroculture™ hardware consists of fluid pumps, fluid delivery and recovery tubes, and rooting matrixes. While several experiments have been performed on growing plants, Astroculture™ is the first attempt to develop a system for the precise watering and nutrient feeding of plants in the microgravity environment, where normal methods do not work effectively.

Purpose: This experiment evaluates a water delivery system to support the growth of plants in microgravity.

Importance: As our stays in space last for longer periods, it will be necessary to grow plants to minimize the costs of life support in space. Plants can reduce the costs of providing food, oxygen and pure water and also lower the costs of removing carbon dioxide in human space habitats. An important step toward designing a system to support plant growth is to find effective ways to supply nutrient solutions for optimizing plant growth and to avoid releasing solutions into the crew quarters. Since fluids behave differently in microgravity, plant watering systems that operate well on Earth do not function effectively in space. This experiment tests a novel nutrient delivery system that will operate under weightlessness or under partial gravity on lunar or Mars bases.

Method: A nutrient delivery system containing a porous tube that circulates nutrient solution under negative pressures will be tested under various conditions. Porous stainless steel tubes are embedded in a particulate medium (baked montmorillinitic clay) that serves as the rooting matrix. Capillary forces will move the solution through the walls of the porous tube. A second porous tube in the matrix simulates the removal of water by the plant root. This second tube will be operated at a greater negative pressure than the first tube. This pressure differential should result in movement of the solution from the supply tube to the recovery tube. Both the supply and recovery tubes will be cycled through various combinations of pressure levels, and scientists will determine the rates at which the solution moves through the root matrix. A computer system will monitor the amount of solution that leaves the reservoir connected to the supply tube and the amount that is pumped into a second reservoir connected to the recovery tube. This will allow data to be collected on the overall capacity of the nutrient solution supply system to replace water and nutrients removed by growing plants in microgravity.

This experiment is the first of a series of tests to evaluate each of the critical subsystems needed for the construction of a reliable plant growth unit. Future experiments will incorporate lighting and atmospheric control subsystems before plants are grown in microgravity using the Astroculture™ unit.



The Astroculture™ experiment is important to all long-term space efforts, such as space stations, lunar bases, and trips to other planets. Plants will be needed for food, air recycling and for the psychological benefits to the people on these missions.

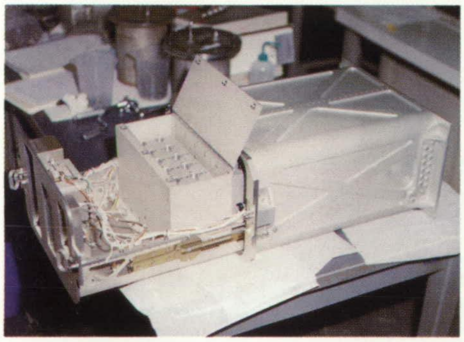
Generic Bioprocessing Apparatus

Principal Investigator: Dr. Michael C. Robinson
Center for Bioserve Space Technologies, University of Colorado

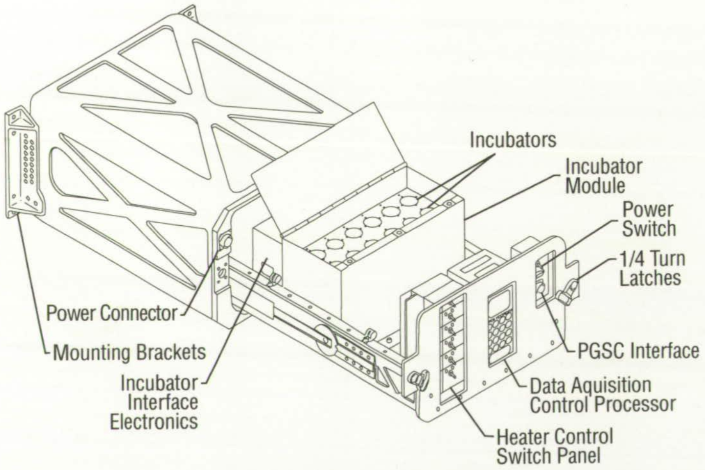
Purpose: This generic research tool allows a variety of relatively sophisticated bioprocessing experiments in microgravity to be performed in one apparatus.

Importance: The Generic Bioprocessing Apparatus is a multipurpose facility that can help us answer important questions about the relationship between gravity and biology. This unique facility allows scientists to study biological processes in samples ranging from molecules to small organisms. The facility supports up to 132 individual experiments of several milliliters volume each. Some specific experiments have already been scheduled for USML-1. Data from flight experiments scheduled on two missions before USML-1 will be evaluated to determine which other experiments can best take advantage of this mission.

Some experiments will study how microgravity affects the assembly behavior of macromolecules. For example, scientists will examine how collagen—a protein substance found in connective tissue, bones, and cartilage—forms fibers. In microgravity, it might be possible to alter collagen fiber assembly so that this material could be used more effectively as artificial skin, blood vessels, and other parts of the body.



The Generic Bioprocessing Apparatus Flight Hardware



The Generic Bioprocessing Apparatus

At the level of complete microstructures, investigators will study the assembly of liposomes and virus capsids, two types of spherical structures that could be used to encapsulate pharmaceuticals. If these biological products can be formed properly, they could be used to target a drug to specific tissues in the body, such as a tumor.

Another experiment examines how mineralization occurs and influences the embryonic bone tissue of rodents. This will help scientists understand how gravity alters tissue development and help explain what causes bone material loss in astronauts exposed to microgravity. These studies relate to Earth biomedical problems such as osteoporosis. Yet another group of experiments will focus upon lymphocytes and macrophages to study microgravity's effects on the immune system.

Experiments with microorganisms will help with the design of ecological waste treatment and water recovery systems needed for long-term stays in space. These experiments will also help scientists learn more about gravity's role on the cellular level and help them identify alterations in bacteria and other microorganisms, which might create health problems for crewmembers living in space during long trips to Mars and other extended duration space missions.

One set of experiments with whole organisms examines the development of brine shrimp and wasp eggs exposed to space. Both organisms will develop significantly during the 13-day mission. Even though the brine shrimp and wasps are simple organisms compared to humans, their development may shed light on the importance of gravity in human development and aging.

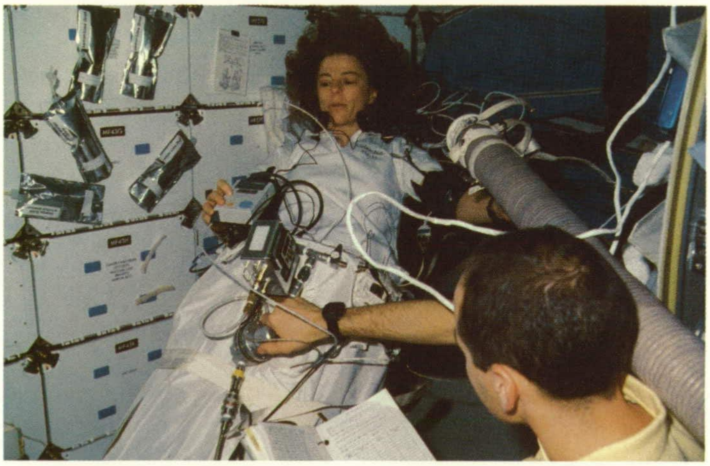
Another experiment will evaluate seed germination and development. This will help develop the technology to grow plants in space and provide knowledge for use in agriculture on Earth.

Method: Bioprocessing reactions can be initiated using both specific mixing and heating protocols. Multiple-step reactions involving sequential mixing of fluids will be possible for phased processing. Simple optical monitoring of turbidity changes are possible. This new capability is a major innovation in the study of biological processes.

A crewmember will insert a batch of 12 samples into the self-contained Generic Bioprocessing Apparatus module and then initiate fluid mixing and incubation. A computer will take data and terminate the incubation automatically after a preprogrammed duration.
A crewmember will remove the samples, store them in the refrigerator, and load another batch of samples for incubation. Some samples may be monitored for brief periods repeatedly throughout the mission. Samples are based in either the refrigerator/incubator module or an ambient temperature storage locker when they are not in the bioprocessing unit. Both data taken on orbit and returned samples provide the basis for analysis. ✪

Extended Duration Orbiter Medical Project

Project Manager: Mr. J. Travis Brown
NASA Johnson Space Center



Payload Commander Dr. Bonnie Dunbar, seen here on a previous mission, will be one of the subjects using Lower Body Negative Pressure on USML-1.

Using the Automatic Blood Pressure Monitor and other equipment, scientists hope to determine if heart rate and blood pressure exhibit more or less variability in microgravity than on Earth.

Purpose: The purpose of the Extended Duration Orbiter Medical Project is to protect crew health and safety during 13- to 16-day missions. On USML-1, the Extended Duration Orbiter Medical Project will have Spacelab, middeck, and pre- and postflight investigations to assess the medical status of the crew. The experiments selected for Spacelab are Lower Body Negative Pressure, Variability of Heart Rate and Blood Pressure, and Microbial Air Sampler.

Importance: The human body undergoes many adaptations to the microgravity environment, including fluid shifts and changes in cardiac function. Some of these changes, which are normal responses to the absence of gravity, may cause problems for the crewmembers upon return to Earth.

Lower Body Negative Pressure: During early phases of a mission, observers may notice that some crewmembers' faces become puffy. This is because fluid shifts from the lower body toward the head and chest in the absence of gravity. While it is not a problem on orbit, the fluid shift and accompanying fluid loss can pose potential problems upon return to Earth. For instance, crewmembers may experience reduced blood flow to the brain when standing up. This could lead to fainting or near-fainting episodes. The investigators hypothesize that redistributing body fluids through exposure to Lower Body Negative Pressure in conjunction with fluid loading and salt tablet consumption will improve this situation and help prevent fainting. The 4-hour treatment, called a "soak," is believed to be effective for 24 hours.

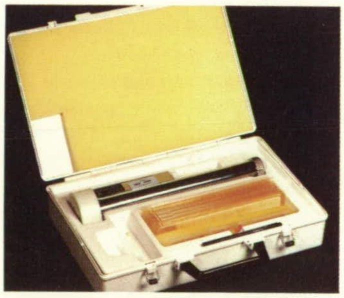
The Lower Body Negative Pressure experiment uses a three-layer collapsible cylinder that seals around the crewmember's waist. The device is tethered to the floor of the Spacelab and stands approximately 5 feet tall. A vent to the vacuum of space is used to create a negative pressure within the device after the crewmember is inside. A controller is used to automatically reduce and increase the pressure according to a preset protocol. Measurements of heart dimensions and function, heart rate and blood pressure will be recorded. Leg volume measurements will be performed before and after each protocol. The data collected will be analyzed to determine physiological changes in the crewmembers and effectiveness of the treatment.

Variability of Heart Rate and Blood Pressure: On Earth, many factors affect heart rate and blood pressure. These include job stress, specific activity, diet, and changes related to sleeping and waking states. While activities and body cycles cause a majority of these fluctuations, gravity also plays a role. This study will determine if blood pressure and heart rate exhibit more or less variability in microgravity than on Earth. The study will also determine whether a change, if any, correlates with the microgravity-induced reduction in sensitivity of baroreceptors in the carotid artery located in the neck. Baroreceptors are one of the body's sensors used to regulate blood pressure and heart rate.

Crewmembers will wear a portable Automatic Blood Pressure Monitor and a Holter Recorder system that continuously records heart activity while periodically monitoring blood pressure in the arm. The data collected are analyzed after the mission.

Microbial Air Sampler: Although all materials that go into the Shuttle are as clean as possible, bacterial and fungal growth have been detected in missions of 6- to 10-days. The growths were minimal and posed no health risk to the crew; however, as missions increase in length, the potential for microbial contamination increases and could affect crew health.

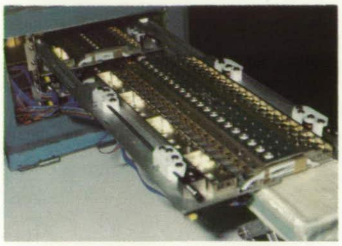
The Microbial Air Sampler is a device that will be used in several areas of the Spacelab. After agar strips are inserted into the device, a small fan pulls air across the agar surface. Postflight analysis of the strips will quantify the fungal and bacterial growth from this 13-day mission.



The Microbial Air Sampler will be used to determine the growth of fungi and bacteria over the course of USML-1's 13-day mission.

Protein Crystal Growth

Principal Investigator: Dr. Charles E. Bugg
Center for Macromolecular Crystallography, The University of Alabama at Birmingham



Twenty crystal growth chambers are contained in a Vapor Diffusion Apparatus like this one, and three such apparatus are contained in a refrigerator/incubator module. Protein Crystal Growth experiments on USML-1 will use three refrigerator/incubator modules: The main experiment will use two (for 120 individual growth chambers), while the Glovebox Protein Crystal Growth Experiment will use one.

Protein crystals are grown in chambers like this one. Differences in vapor pressure cause water to leave the protein solution drop, causing it to become more concentrated. As the concentration increases, crystals begin to grow. In microgravity, scientists have been able to grow larger and more nearly perfect crystals than can be grown on Earth.

Purpose: This experiment grows crystals of various proteins for study and investigates the kinetics of crystal growth and the way fluid disturbances cause defects in crystals.

Importance: Proteins play important roles in everyday life, from providing nourishment to fighting disease. Scientists want to explore what each protein does and how its structure determines its function. X-ray crystallography is the most widely used method for determining the three-dimensional structures of proteins, but it requires large, single protein crystals for analysis. (It should be noted, however, that even large protein crystals (1 mm) are miniscule compared to the inorganic crystals being grown in the Crystal Growth Facility.) For proteins, a large crystal is about the size of a grain of table salt. Earth-grown crystals large enough to study often have numerous flaws caused by gravity. Gravity-induced sedimentation and convection hamper efforts to produce flawless crystals that are large enough to study. Crystals grown in microgravity tend to be larger and have more uniform internal structures, allowing much better X-ray diffraction studies of those structures. Studies of such crystals not only provide information on basic biological processes but also could lead to the development of foods with higher protein content, highly resistant crops, and more effective drugs.

By also studying the kinetics, or growth rates under differing conditions, investigators can find ways to improve the growth of protein crystals in microgravity. This will lead to higher quality crystals for study and to the ability to produce large crystals of hard-to-grow proteins.

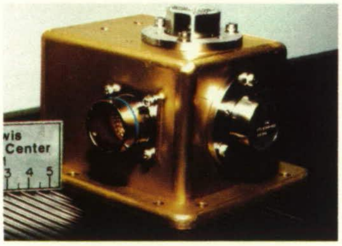
For these reasons, the Protein Crystal Growth experiment has flown on several previous missions. Of the 32 candidate proteins for USML-1, one-third have flown on previous flights. Examples of two candidate proteins and their importance are Neuraminidase, an enzyme on the surface of the influenza virus that enables the virus to spread in the body, and reverse transcriptase, an enzyme that is a chemical key to the replication of the AIDS virus. The crystalline structure of these proteins will be used to gain a better understanding of their biological functions and may be of value in the design of drugs used as specific treatments for the diseases associated with these proteins. Other candidate proteins may lead to a better understanding of the immune system, diseases, protein processing in the body, and the activation/deactivation of individual genes. The proteins that will be flown are selected a few months before launch.

Method: The USML-1 Protein Crystal Growth experiment consists of three middeck refrigerator/incubator modules, which provide constant temperatures for crystal growth. One will provide a temperature of 4 °C, and the other two will maintain a temperature of 22 °C. Experiments to be activated in the Spacelab Glovebox will be contained in one of the 22 °C modules. Each of the two remaining modules for the Protein Crystal Growth experiment holds three Vapor Diffusion Apparatuses, containing 20 individual crystal growth chambers each. One side of each Vapor Diffusion Apparatus holds 20 double-barrelled syringes, one per chamber, while the other side consists of ganged plugs that extend into the tips of the syringes. One barrel of each syringe contains a buffered protein solution; the other houses a precipitant solution that causes the crystals to grow. A reservoir of concentrated precipitant solution surrounds each growth chamber.

To activate the experiment, a crewmember will attach a handwheel to the plug side of a Vapor Diffusion Apparatus and turn it to retract the plugs from the syringe tips. The handwheel will then be moved to the syringe side, where it is turned back and forth several times to mix the two solutions. The crewmember will then turn the handwheel to extrude a drop on the tip of each syringe. Vapor pressure differential within each chamber, caused by the difference in precipitant concentration, will cause water to migrate from the drop on the syringe tip to the solution in the reservoir. As the concentration of the precipitant solution increases in the drop, crystal growth will begin. Crewmembers will photograph crystal growth in the 22 °C refrigerator/incubator Vapor Diffusion Apparatuses at various times during the mission. When the experiment is complete, the drops containing the crystals will be withdrawn into the syringes for postflight examination.

Space Acceleration Measurement System

Project Manager: Mr. Richard DeLombard
NASA Lewis Research Center

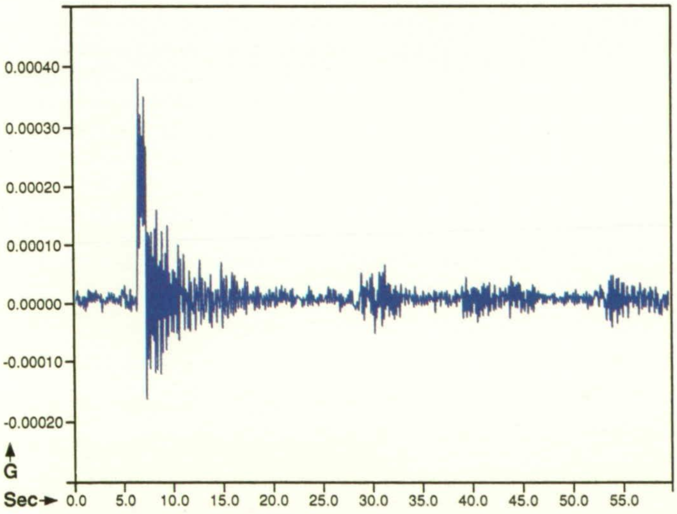


Three triaxial sensor heads, like this one, will be located in different parts of the Spacelab module during USML-1. Each head sends data back to the central processing unit, mounted in the center aisle of the module.

Purpose: This facility measures the acceleration environment of Spacelab using remote triaxial sensor heads.

Importance: Microgravity is an ideal environment in which to conduct many different types of research. Away from the effects of Earth's gravity and vibrations, scientists can produce purer products, more uniform mixtures—including some not possible on Earth because of differences in the weights of the component materials—and larger, more nearly perfect crystals.

Microgravity, however, as its name suggests, is not the absence of gravity. Although the effects of Earth's gravity are significantly reduced, they are not eliminated. Crew movements, equipment operations, and Shuttle maneuvers can produce vibrations that mimic the effects of gravity. To help scientists conducting experiments on USML-1 know the strength and frequency of the vibrations that may have affected their experiments, the Space Acceleration Measurement System is making its fourth flight on USML-1.



This typical Space Acceleration Measurement System data plot, obtained on the Spacelab Life Sciences-1 mission (STS-40), shows a portion of the x-axis acceleration data from a triaxial sensor head that was mounted to the Solid Surface Combustion Experiment. Scientists conducting experiments can obtain data from one or all three remote sensor heads to determine the acceleration environment to which the experiment was exposed during the mission.

The Space Acceleration Measurement System records acceleration forces in three locations within the Spacelab module. Sensors will be on or near experiments that require precise measurements of the microgravity environment during operations. These sensor heads, located around the module, will help to "map" the module. The data not only benefit the scientists taking part in USML-1 but also serve to further characterize the Spacelab acceleration environment. This characterization, conducted as part of the Acceleration Characterization and Analysis Project, assists in planning future missions by identifying the most advantageous location to place experiments that are extremely sensitive to vibrations and accelerations and by providing guidance to scientists and engineers who design experiments and equipment for Spacelab.

Method: The Space Acceleration Measurement System has three triaxial sensor heads that measure accelerations along three orthogonal axes at separate locations in the Spacelab module. Each sensor head has three inertial sensors that measure both positive and negative accelerations over a specific range of frequencies. The Space Acceleration Measurement System team has worked with other USML-1 investigators before the mission to select the frequencies to be measured and the location of the sensor heads. Each head also measures local temperature and contains the necessary electronics to filter and amplify the signals from the sensors.

The USML-1 Space Acceleration Measurement System sensor heads are placed on the internal support structures of the Surface Tension Driven Convection experiment and the Crystal Growth Furnace and on the Glovebox below the work space. Data collected at each location will be transmitted to a central unit, where it is converted to a digital signal and stored on optical disks. This unit will be located in the center of the Spacelab aisle on USML-1 and uses a microprocessor to control its operations. The optical disks can hold 400 megabytes of data each, and approximately 2 gigabytes of raw data are expected to be acquired on the mission.

These raw data will be processed for bias and temperature effects and provided to interested scientists and investigators after the mission. Investigators not involved with the experiments where the sensor heads are located can use data from either the sensor head closest to their experiment or the combined data from all three sensor heads.

While not a part of the USML-1 payload but a part of the ongoing Orbiter Experiments Program, the Orbital Acceleration Research Experiment will measure the other area of concern to scientists and equipment designers: quasi-steady accelerations caused by drag and vehicle rotation. By gathering data on these two types of accelerations, scientists can better understand the results obtained on USML-1 and improve the designs of future experiments and space structures. ✪

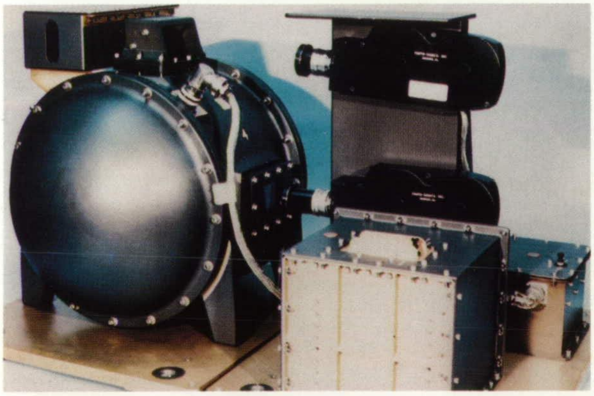
Solid Surface Combustion Experiment

Principal Investigator: Dr. Robert A. Altenkirch
Mississippi State University

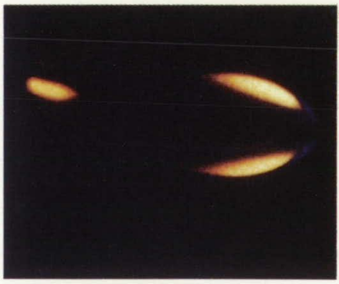
Purpose: This experiment studies the way flames spread over solid fuels in an environment where gravity-driven buoyant and externally imposed air flows are absent.

Importance: The physical and chemical mechanisms that cause flames to spread on Earth are different in the low-gravity of an orbiting spacecraft. It is well known that material flammability and flame spread rates are strongly affected by the environment, including oxygen content, pressure, and convective air flow. However, the effects of these conditions in the microgravity environment are unknown. Scientists must understand what might evoke flames in microgravity and use this knowledge to evaluate fire hazards aboard spacecraft.

Method: A sample of ashless filter paper will be sealed in a chamber with an atmosphere that supports combustion. A hot filament wire coated with nitrocellulose will ignite the sample. Two windows in the chamber will allow two 16-mm cameras to film an edge (side) and a surface (top) view of the sample, so the flame spread rate can be determined. A temperature sensor and a pressure transducer will measure the internal chamber temperature and pressure. Thermocouples located on and near the sample will measure the solid- and gas-phase temperatures. These temperatures and the spread rate will be used to determine the heat transfer rates from the flame to the fuel, which will provide information on the mechanisms of flame spreading at near zero gravity. From this, scientists hope to determine why these flames propagate. ✪



The Solid Surface Combustion Experiment hardware consists of a combustion vessel and the equipment to control the experiment and record data. Two cameras record the actual combustion, providing both front and top views. Other data are gathered electronically.

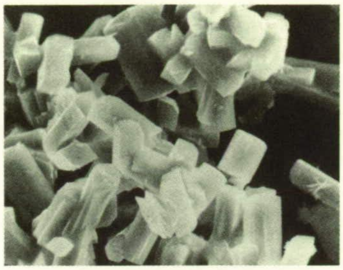


This photograph comes from camera images obtained during a test on a previous mission. The film record shows the ignition and spread of flames over the surface of the flammable material.

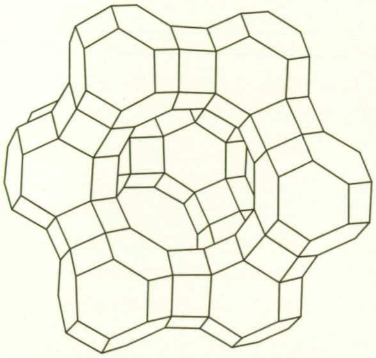
ORIGINAL PAGE
COLOR PHOTOGRAPH

Zeolite Crystal Growth

Principal Investigator: Dr. Albert Sacco, Jr. (Worcester Polytechnic Institute)
Battelle Advanced Materials Center, Clarkson Center for Commercial Crystal Growth in Space



A photomicrograph of a zeolite crystal

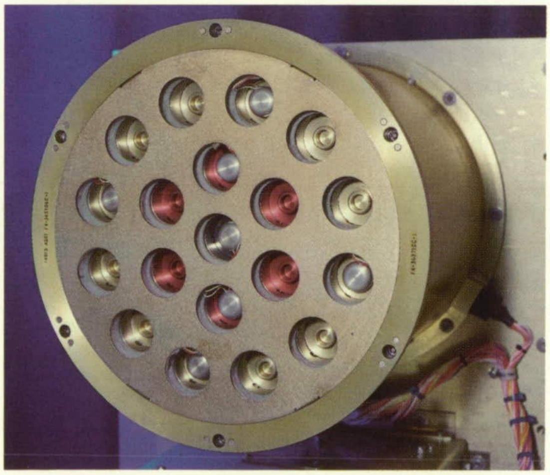


A drawing of a typical zeolite crystal

Purpose: This experiment evaluates the synthesis of large zeolite crystals in microgravity.

Importance: Zeolite crystals currently are used in the chemical process industry as catalysts and adsorbents (filters). Their three-dimensional crystal structure is capable of selective adsorption (filtration), so zeolite crystals are often used as molecular "sieves." If large zeolite crystals, 500 to 1,000 times the size grown on Earth, can be grown in microgravity, scientists will better understand their crystalline structure. This knowledge could help improve existing catalytic and adsorbent processes. In addition, if the microgravity-grown crystals are large enough and have nearly perfect crystalline structures, they could be used as industrial membranes. Zeolite membranes could result in major advantages over current separation and catalytic processes.

Because of the potential for zeolite crystals, this experiment is the combined effort of two Centers for the Commercial Development of Space, Battelle Advanced Materials Center and Clarkson Center for Commercial Crystal Growth in Space, and their industry partners.



Once activated and assembled, the autoclaves are placed in the Zeolite Crystal Growth Furnace, the front cover is secured, and the furnace is activated. The entire assembly fits in the space of two middeck stowage lockers.

Method: The Zeolite Crystal Growth experiment fits in the space of two middeck lockers and consists of 38 autoclaves that will be activated and loaded into the cylindrical Zeolite Crystal Growth furnace assembly. Because zeolite synthesis begins with the initial mixing of the two source solutions, one aluminum-based and the other silicon-based, the autoclaves were designed to be loaded on Earth for mixing in orbit. They were also designed for ease of installation into and removal from the furnace.

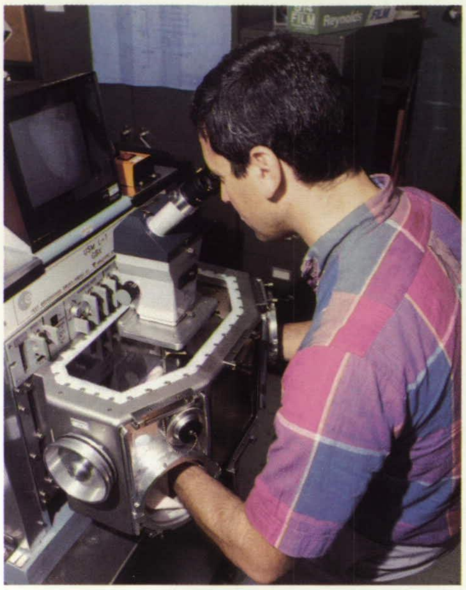
Each metal autoclave contains two chambers and a screw assembly. By turning the screw assembly with a powered screwdriver, the solution in one chamber is pressurized and forced into the main chamber. Turning the screw in the opposite direction pulls fluid back into the emptied chamber. By repeating this process several times, proper mixing of the two solutions can be obtained. On USML-1, several different nozzle designs and mixing aids are being used. Experiments conducted in the Glovebox using clear autoclaves will determine the proper number of times the fluids should be worked to ensure proper mixing for each design.

The furnace assembly consists of 19 heater tubes/support structures, each holding two autoclaves, surrounded by insulation and an outer shell. The furnace automatically processes the multiple samples in three independently controlled temperature zones of 175 °C, 105 °C, and 95 °C.

Once all the autoclaves have been activated and loaded into the furnace assembly, a cover is secured over the front of the furnace assembly and the furnace activated. Every 2 hours during the experiment, the furnace is checked for proper operations. Once the experiment has been completed, the autoclaves will be removed and stored for landing. After the mission, scientists will determine which hardware and growth conditions were optimum and examine the crystals produced.

On USML-1, the zeolite crystals will be grown in 38 individual autoclaves similar to these engineering models. Two autoclaves are joined together before being placed in the furnace. While externally the same, there are several types of internal arrangements that will be tested to determine which one provides the best mixing of the component solutions.

Glovebox



Payload Specialist Dr. Lawrence DeLucas tests a microscope for USML-1 on the engineering mockup of the Glovebox

The Spacelab Glovebox, provided by the European Space Agency, offers experimenters a new capability to test and develop science procedures and technologies in microgravity. It enables crewmembers to handle, transfer, and otherwise manipulate materials in ways that are impractical in the open Spacelab. The facility is equipped with photographic equipment that allows a visual record to be made of experiment operations. Many investigations will benefit from the increased crew involvement and photographic/video capabilities that the facility permits.

The Glovebox has an enclosed compartment that offers a clean working space and minimizes the contamination risks to both Spacelab and experiment samples. It provides two types of containment for small quantities of materials: physical isolation and negative air pressure differential between the enclosure and the rest of the Spacelab working area. An air-filtering system also protects the Spacelab environment from experiment products that could be harmful to the crew.

Although fluid containment and ease of cleanup are major benefits provided by the facility, it can also contain powders, bioparticles, and other debris produced during experiment operations. Even toxic, irritating, or potentially infectious materials can be prevented from entering the Spacelab environment. While this "safety cabinet" prevents leaks or spills into Spacelab, it also protects samples from contamination when experiment procedures call for containers to be opened.

The facility provides the following services to microgravity experiments: a large viewing window atop the cabinet, experiment mounting and positioning equipment, real-time downlink of experiment video and housekeeping data, electrical power, partial temperature control, a time-temperature display, lighting, and cleaning supplies. It has six video camera heads (three black-and-white and three color) to record experiment operations and the behavior of specimens, a backlight panel, a 35-mm camera, and a stereomicroscope that offers high-magnification viewing and

1

Passive Accelerometer System

Dr. J. Iwan D. Alexander
The University of Alabama in Huntsville

Purpose: To measure the low-level accelerations caused by atmospheric drag and the Shuttle's gravity-gradient attitude

Importance: Because many microgravity experiments and processes are sensitive to accelerations, even low-level motions that are difficult to measure, it is important to measure these accelerations to improve the design of future experiments and facilities.

2

Interface Configuration Experiment

Dr. Paul Concus
University of California, Berkeley, and Lawrence Berkeley Laboratory

Purpose: To investigate the shape that fluid surfaces may assume for specific containers in microgravity

Importance: Free liquid/vapor interfaces in microgravity cannot yet be predicted satisfactorily. Because many on orbit operations involve fluids and depend on their behaviors, it is important to test and refine models used to determine how container geometry and motion affect the location and shape of fluid surfaces.

3

Protein Crystal Growth Glovebox Experiment

Dr. Lawrence J. DeLucas
The University of Alabama at Birmingham

Purpose: To identify optimal conditions for nucleating and growing protein crystals from solution in space

Importance: By analyzing protein crystals, scientists may be able to develop dramatically better medical and agricultural products. To improve the quality of protein crystals grown in space, more information is needed about optimum mixing times, solution concentrations, and other growth parameters.

4

Solid Surface Wetting Experiment

Dr. Eugene H. Trinh
NASA Jet Propulsion Laboratory

Purpose: To determine the best tip shape for injectors that deploy drops in the Drop Physics Module; to identify the optimal surface treatment for such tips

Importance: Complex experiments in the Drop Physics Module depend on proper samples and the efficiency and accuracy with which investigators can deploy, manipulate, and measure drop volume and shape.

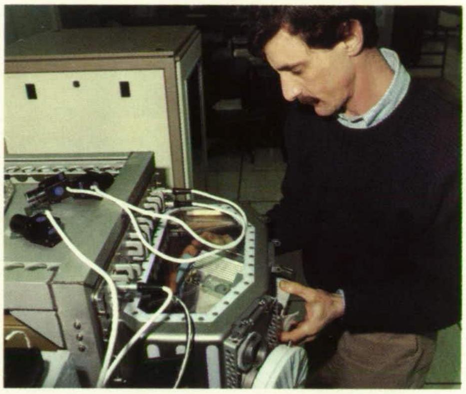
the capability to record images when used in concert with the video or still cameras.

The crew manipulates samples or experiment equipment through three doors: a central port through which experiments are placed in the Glovebox and two glovedoors. The glovedoors are located on each side of the central port and serve three functions. When an airtight seal is required, the crew inserts their hands into rugged gloves attached to the glovedoors, and no airflow occurs between the enclosure and the Spacelab. If the experiment requires more sensitive handling than allowed by the rugged gloves, the crew may don surgical gloves and insert their arms through a set of adjustable cuffs. Each of the glovedoors also provides a viewport for the facility's charge-coupled device cameras.

General operations require the crew to unstow experiment modules and specimens, move these to the enclosure, and place these inside. Most of the experiment modules have magnetic bases or strips that hold them to the steel floor of the enclosure, while others attach to a laboratory jack in the enclosure that can position the module at a chosen height above the cabinet floor. Experiment equipment may also be bolted to the left wall of the working space or attached outside the facility with Velcro™.

Once the experiment equipment is secured, the crew will proceed with operations specific to a particular investigation. Following the experiment, the crew will clean up any spills or leaks in the workspace, reassemble the hardware if necessary, and move it back into stowage. They will also store any samples that must be preserved for postflight analysis.

For the USML-1 mission, the Glovebox experiments fall into four basic categories: fluid dynamics, combustion science, crystal growth, and technology demonstration. Crewmembers will conduct 16 experiments that test or demonstrate microgravity science theories, procedures, and hardware related to this broad range of materials science activities. Some of



An experimenter practices loading equipment through the front entrance of the engineering mockup of the Glovebox during testing for USML-1.

5

Marangoni Convection in Closed Containers

Dr. Robert J. Naumann
The University of Alabama in Huntsville

Purpose: To determine whether surface tension driven convection can occur in closed containers in microgravity and under what conditions

Importance: A liquid in space may not conform to the shape of its container; therefore, it may be possible for Marangoni convection to occur along all free surfaces of a liquid. If so, models of Marangoni convection effects on heat transfer and fluid motion in space must be refined.

6

Smoldering Combustion in Microgravity

Dr. A. Carlos Fernandez-Pello
University of California, Berkeley

Purpose: To observe the smoldering characteristics of polyurethane in microgravity

Importance: Smoldering fires are especially dangerous because the inside of a material can smolder undetected at a low intensity for long periods before bursting into flames. Information about smoldering combustion in space will help to develop ways of preventing, detecting, and extinguishing smoldering fires in spacecraft and on Earth.

7

Wire Insulation Flammability Experiment

Mr. Paul S. Greenberg
NASA Lewis Research Center

Purpose: To examine the ignition and combustion of electrical wire insulation in microgravity

Importance: One of the principal potential sources of fire aboard a spacecraft is the overheating of electrical systems. For improved safety, it is necessary to understand how fires originating in electrical wiring might occur in space and how the offgassing and combustion behave. Results have implications for the detection and extinguishment of fires in space and provide insight into material flammability testing for space applications

8

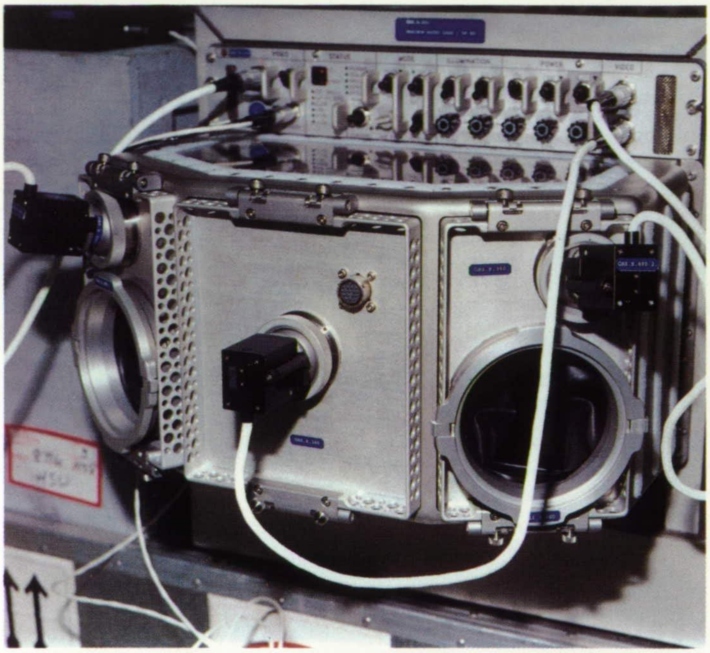
Candle Flames in Microgravity

Dr. Howard D. Ross
NASA Lewis Research Center

Purpose: To examine whether candle flames can be sustained in space; to study the interaction and physical properties of diffusion flames

Importance: In space, where buoyancy-driven convection is reduced, the role diffusion plays in sustaining candle flames can be isolated. Results have implications for other diffusion flame studies. Diffusion flames are the most common type of flame on Earth.

Glovebox



The Glovebox

these experiments will also provide information that other USML-1 investigations will use immediately during the mission to refine their experiment operations.

Seven fluid dynamics experiments focus both on basic fluid phenomena and how these affect materials processing and on the development of technologies that may enhance the study of fluid behavior in space. The investigations examine factors influencing the behavior of liquids in the absence of gravity: causes of surface movement in free liquids, the degree of contact between a liquid and its container, bubble formation and movement, and the comparative strength of subtle forces during fluid processing. They also demonstrate techniques for deploying liquid drops in microgravity.

Three combustion science experiments examine the important role of subtle forces that are usually masked by Earth's gravity. These studies seek to increase knowledge of how combustion—whether it results in smoldering or open flames—occurs in space. Findings may be applicable to operations that produce flames and to improved safety features in spacecraft.

The Glovebox will also support three experiments that grow zeolite and protein crystals. These activities will test and refine techniques for growing crystals in space.

In the realm of technology demonstration, one experiment will assess whether a material representing a potential breakthrough for medical implantation can be produced effectively in space. Another will demonstrate a new means of gathering microgravity accelerometer data, while a third will test a method for creating fine particle clouds.

9

Fiber Pulling in Microgravity

Dr. Robert J. Naumann
The University of Alabama in Huntsville

Purpose: To investigate the advantages of pulling optical fibers in space

Importance: On Earth, gravity drainage and Rayleigh-Taylor instabilities cause thin columns of low-viscosity liquids to break apart or form beads. In space, it should be possible to determine which of the two influences is the limiting factor in fiber pulling and whether certain low-viscosity materials could be more efficiently processed in microgravity.

10

Nucleation of Crystals from Solutions in a Low-g Environment

Dr. Roger L. Kroes
NASA Marshall Space Flight Center

Purpose: To demonstrate and evaluate a new technique for initiating and controlling the nucleation of crystals in a solution

Importance: An improved ability to control the location and time of the onset of nucleation of crystals in a solution has the potential to increase the flexibility of all space experiments involving solution crystal growth.

11

Oscillatory Dynamics of Single Bubbles and Agglomeration in an Ultrasonic Sound Field in Microgravity

Dr. Philip L. Marston
Washington State University

Purpose: To explore how large and small bubbles behave in space in response to an ultrasound stimulus

Importance: The oscillations and dynamics of large bubbles should be more easily observed in space than on Earth. By understanding how the shape and behavior of bubbles change in response to ultrasound in a liquid, it may be possible to develop techniques that eliminate or counteract the complications that small bubbles cause during materials processing.

12

Stability of a Double Float Zone

Dr. Robert J. Naumann
The University of Alabama in Huntsville

Purpose: To determine if a solid cylinder can be supported by two liquid columns and remain stable in space

Importance: It may be possible to increase the purity and efficiency of glass materials with a newly patented technique that relies on a solid column of material supported by two liquid columns of its own melt. If this arrangement can be maintained in microgravity, space may be a suitable laboratory for such processing.

Mission Planning and Operations

The USML-1 Investigator Working Group

Organizing the unique blend of scientific talent and systems required for a vanguard mission like USML-1 is a challenge. Overall management responsibility for the mission resides with the program manager, while the program scientist supervises science development. The mission manager is responsible for payload integration, crew training, planning the mission, managing the payload and its operations during the mission, associated scheduling, and day-to-day operations. The mission scientist oversees day-to-day science activities and serves as the interface between the principal investigators for the experiments and the mission manager.

Planning for the mission began more than 5 years ago when the USML program was initiated in 1987. Since that time, 31 experiments have been selected for this first flight of USML. The principal investigators form the core of the USML-1 Investigator Working Group. The Investigator Working Group meets to review the development of experiments and hardware, modifications, and the addition of new experiments. They coordinate the experiments to match Spacelab power, data collection, and space capabilities so that the maximum scientific return can be obtained for the mission. The group also recommends selection of the payload specialists who will fly on the mission. Through the mission scientist, who chairs the Investigator Working Group, they advise the mission management team on science issues.

Slightly more than 2 years before launch, the teamwork that is necessary for the mission begins to develop. The teams for each experiment, the hardware developers, the crew, and teams at various ground facilities come together to form a single cadre for the mission.

This process begins with crew training. The payload crew (two mission specialists and two payload specialists) travel to laboratories around the country to learn the basic science behind each experiment and the procedures to be used and to gain the skills necessary to perform the different experiments. They simulate both individual experiments and combined operations at the Payload Crew Training Complex at the Marshall Space Flight Center in Huntsville, Alabama. The combined operations training involves practicing the activities that will occur during sections of the mission timeline, which is a schedule detailing all the activities to be performed during the mission. The timeline is developed by a team of engineers who works with the Investigator Working Group and mission management to provide balanced use of limited resources, such as power and crew time, for all experiments.

While the payload crew is training in both the principal investigators' laboratories and the Payload Crew Training Complex, the flight crew (the commander, pilot, and one mission specialist) is practicing their portion of the mission in simulators at the Johnson Space Center in Houston, Texas. Also at Johnson, the flight director and his team practice controlling the flight in the Mission Control Center.

As the year progresses, all the different elements of the USML-1 mission are brought together in Joint Integrated Simulations. These simulations tie together mission control, the flight crew, the payload crew, investigator teams, and support crews to form the mission cadre. During these simulations, the cadre prepares for both routine operations and those required should equipment or systems fail to operate as planned.

Also during this time, the hardware developed for the mission is shipped

USML-1 Mission Management Team

Mission Manager
Mr. Charles Sprinkle
MSFC

Asst. Mission Manager
Mr. Paul Gilbert
MSFC

Program Manager
Mr. Jim McGuire
NASA Headquarters

Program Scientist
Dr. Roger Crouch
NASA Headquarters

Mission Scientist
Dr. Donald Frazier
MSFC

Asst. Mission Scientist
Ms. Barbara Facemire
MSFC

System Capabilities

- **Equipment**

Color video monitor

Stereomicroscope

35-mm camera

Black-and-white video heads (3)

Color video heads (3)

Laboratory jack

Back light panel

Wall lights

Stray light covers

Scavenge pump

Time-temperature display

- **Capabilities**

Gloveports (2) with attachments for gloves or adjustable cuffs and adapters for cameras

Filtration system

Heat exchanger

Electrical outlets: +24 V, +12 V, -12 V, +5 V

Gas sensors

Temperature sensors

Pressure sensors

Humidity sensors

Working and stowage volume: 25 liters

Stowage: 75 kg

13

Oscillatory Thermocapillary Flow Experiment

Dr. Simon Ostrach
Case Western Reserve University

Purpose: To determine the conditions for the onset of oscillations in thermocapillary flows in silicone oils

Importance: Temperature variations along a free liquid surface generate thermocapillary flows in the bulk fluid. On Earth, the flows become oscillatory under certain conditions. By determining the conditions present when oscillations begin in microgravity and comparing them to oscillatory onset conditions on Earth, scientists will gain insight into the cause of the oscillations.

14

Particle Dispersion Experiment

Dr. John R. Marshall
NASA Ames Research Center

Purpose: To investigate how fine particles aggregate in air; to evaluate a technique for dispersing particles uniformly as a starting point for aggregation experiments

Importance: By understanding how dust particles in an atmosphere form aggregates and by developing a concept of the natural end-product of aggregation, scientists can better assess how planetary atmospheres are cleansed of dust.

15

Directed Orientation of Polymerizing Collagen Fibers

Dr. Louis S. Stodieck
Center for Bioserve Space Technologies

Purpose: To demonstrate that the orientation of collagen fiber polymers can be directed in microgravity in the absence of fluid mixing effects

Importance: Collagen polymers have potential uses as synthetic implant materials; they are readily available, compatible with the immune system, and made of biological components. The orientation of collagen fiber polymers is critical to their functions, and gravity-driven mixing on Earth interferes with the ability to direct the required orientation of these fibers on Earth.

16

Zeolite Glovebox Experiment

Dr. Albert Sacco, Jr.
Worcester Polytechnic Institute

Purpose: To examine and evaluate mixing procedures and nozzle designs that will enhance the middeck Zeolite Crystal Growth experiment; to observe when and where crystal nucleation occurs

Importance: Zeolite crystals are used as catalysts and filters. To grow useable crystals, the growth solutions must be mixed precisely. A middeck zeolite growth experiment relies on this investigation to provide information that will result in the most efficient procedures and equipment to produce good quality crystals.

Launch

to the Kennedy Space Center in Florida, tested, and installed into equipment racks and the racks placed into a Spacelab long module. Testing throughout this process helps ensure that the hardware works on an individual basis and as an integrated whole. The completed module is then loaded into the cargo bay of the orbiter, and further tests are conducted to check the combined operations of both Shuttle and Spacelab systems.

Though the flight of the orbiter is controlled from the Mission Control Center at Johnson, the science portion of the mission—the operation of the scientific experiments—is controlled from Spacelab Mission Operations Control at the Marshall Space Flight Center. This facility is the nerve center for USML-1 science operations.

Activation

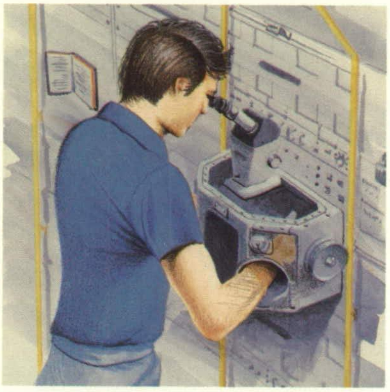
At Spacelab Mission Operations Control, the mission manager and his team oversee the operation of the Spacelab payload and monitor the progress of the mission. In the Science Operations Area, the individual experiment teams monitor their experiments, receive data, and formulate changes to procedures as needed. If necessary, they can even talk directly with the crewmembers working on their experiments, providing a level of interaction that will help maximize scientific return from the mission.

Mission management and the science teams are supported by hardware, systems, replanning, and communications teams also located at Spacelab Mission Operations Control. The hardware teams monitor individual facilities, such as the Crystal Growth Furnace; systems teams monitor larger items, such as Spacelab thermal control, power, and environmental control systems; the replan teams create new timelines as changes occur during the mission; and the communications teams oversee both interfacility communications and communications with the orbiter.

The mission cadre works together to ensure the maximum return for USML-1. Potential problems are identified and steps taken to prevent them. If problems develop, they are identified and evaluated, and the best possible solution is implemented. The progress of USML-1 is reflected in the people making up the cadre, from the frustration in a voice when something does not go as planned to the elation of a scientist when the first data appears on the screen.

Upon reaching orbit, the crew operates in two shifts. One shift prepares the Spacelab module and begins work. The other shift goes to sleep as soon as possible. These two shifts will work opposite each other during the mission so that experimentation continues 24 hours a day. The Shuttle is placed in a special nose-up attitude that will orient the Crystal Growth Furnace to the direction of flight and minimize thruster firings. This helps ensure that any residual gravity and acceleration forces from attitude corrections interfere with crystal growth as little as possible.

Lower Body Negative Pressure Operations



Glovebox Operations

The Investigator Working Group meets each day as the Science Operations Planning Group to discuss the events that have occurred since the last meeting. The scientists decide how best to take advantage of these events or meet the challenges they pose, and what—if any—changes are needed in the sequence of upcoming events. With the support of the diverse elements of the cadre, they work to ensure that changes to one experiment do not affect any of the others adversely and that critical resources are shared to the benefit of all.

On the twelfth day of the mission, the crew deactivates Spacelab. They finish experiments, store products—such as crystals and data—generated over the course of the mission, and power down the various systems. The sleep cycles of the two shifts are merged again, and the crew spends the last day preparing for landing at Dryden Flight Research Facility in California. ✪

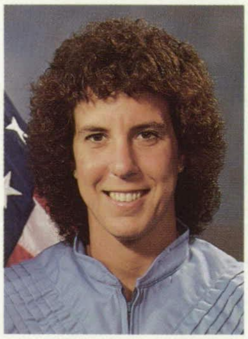
USML-1 Crew

The experiments carried on USML-1 are at the forefront of efforts to advance microgravity materials processing research. A research effort such as this requires far more than just a team of scientists and engineers to put the hardware and procedures in place. It requires knowledgeable control of and interaction with the experiments as they take place by crewmembers who are an integral part of the science team. The USML-1 crew consists of five career NASA astronauts and two payload specialists, scientists who have trained specifically for this mission. Two other payload specialists are alternates and will work in Spacelab Mission Operations Control during the mission. Should one of the flight payload specialists be unable to fly, the appropriate alternate would fly instead.

Mission Commander Richard (Dick) N. Richards will be on his third spaceflight. He is a U.S. Navy Captain and has a B.S. in chemical engineering from the University of Missouri and an M.S. in aeronautical systems from the University of West Florida. He began his career flying support missions in A-4 Skyhawks and F-4 Phantoms and later served aboard the *USS America* and *USS Saratoga*. Following training at the U.S. Naval Test Pilot School, Richards had a tour at the Strike Aircraft Test Directorate. He then served as a project test pilot for automatic carrier landing systems and accomplished the first shipboard catapult and arrested landings of F/A-18As aboard the *USS America*. Richards became an astronaut in 1980, and his first assignment was as a pilot on STS-28, a Department of Defense (DoD) mission. He then served as commander on STS-41, which successfully deployed the Ulysses spacecraft. He also performed a materials science experiment, the Solid Surface Combustion Experiment, as well as other mid-deck experiments during this mission.

Pilot Kenneth D. Bowersox will be on his first flight. He is a U.S. Navy Lieutenant Commander and has a B.S. in aerospace engineering from the U.S. Naval Academy and an M.S. in mechanical engineering from Columbia University. He began flying as a naval aviator assigned to an attack squadron aboard the *USS Enterprise* where he flew A-7Es. After completion of the U.S. Air Force Test Pilot School, which he attended as part of an interservice exchange program, he served as a test pilot at the China Lake Naval Weapons Center. Since joining the astronaut corps in 1987, Bowersox has served in a variety of technical assignments, including Technical Assistant to the Director of Flight Crew Operations, testing flight software in the Shuttle Avionics Integration Laboratory, and as CAPCOM, or capsule communicator, during several missions.

Payload Commander Bonnie J. Dunbar [Mission Specialist 1 (MS-1)] will be on her third mission. She has a B.S. and an M.S. in ceramic engineering from the University of Washington and a Ph.D. in biomedical engineering from the University of Houston where she is an adjunct professor in mechanical engineering. She has conducted research on ionic diffusion in sodium beta-alumina and on wetting behavior of liquids on solid substrates and has examined the effects of simulated spaceflight on bone strength and fracture toughness. Dr. Dunbar has also worked on the Space Shuttle thermal protection system and evaluated prospective space industrialization concepts for Rockwell International. In addition, she is a private pilot and has co-pilot experience in T-38s. Dunbar started at NASA in 1978 as a payload officer/flight controller, served as guidance and navigation officer for Skylab re-entry, and became an astronaut in 1981. During her first mission, STS-61A, the West German D-1 Spacelab mission, she performed materials science and physiology experiments. On her second mission, STS-32, she retrieved the Long-Duration Exposure Facility using the Shuttle's robot arm, was principal investigator on the Microgravity Disturbance Experiment, and performed medical tests evaluating human adaptation to extended duration missions. Dr. Dunbar will be responsible for Spacelab operations on the Red shift.

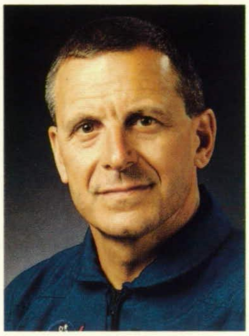


Mission Specialist Dr. Ellen S. Baker, M.D., [Mission Specialist 2 (MS-2)] will be on her second flight. She has a B.A. in geology from the State University of New York at Buffalo and a M.D. from Cornell University. She served a 3-year residency in internal medicine at the University of Texas Health Science Center in San Antonio and was certified by the American Board of Internal Medicine. She joined NASA in 1981 as a medical officer following her residency and graduated from the U.S. Air Force Aerospace Medicine Primary Course at Brooks Air Force Base that same year. She was selected as an astronaut candidate in 1984 and completed her training a year later. She has been involved in flight crew procedures, flight software verification, operations and engineering support activities, and space station support activities. She served as a mission specialist on STS-34, which deployed the Galileo spacecraft and conducted other research.

Mission Specialist Carl J. Meade [Mission Specialist 3 (MS-3)] will be on his second flight. He is a U.S. Air Force Colonel and has a B.S. in electronics engineering from the University of Texas and an M.S. in electronics engineering from the California Institute of Technology. Following his time as a Hughes Fellow at the California Institute of Technology and as an electronics engineer at Hughes Aircraft, he entered the Air Force and completed Undergraduate Pilot Training. After serving as a pilot in a tactical wing, he attended the U.S. Air Force Test Pilot School and later conducted test and evaluation of various fighter aircraft, weapons systems, and cruise missiles. Meade later returned to the Test Pilot School as an instructor. He was selected to become an astronaut in 1985 and has been involved in verification testing of flight software in the Shuttle Avionics Integration Laboratory, crew escape flight tests, orbiter ground egress tests, and launch support duties. He also served as a representative to the Solid Rocket Booster and the Space Shuttle Main Engine programs. Meade first flew as mission specialist on STS-38, a DoD mission. Col. Meade will be responsible for Spacelab operations on the Blue shift.

Payload Specialist (Crystal Growth) Lawrence J. DeLucas [Payload Specialist 1 (PS-1)] is professor of optometry, director of the Purification and Crystallization Laboratory, and associate director of the Center for Macromolecular Crystallography at The University of Alabama at Birmingham (UAB). He holds a B.S. and an M.S. in chemistry, a B.S. in physiological optics, an O.D. in optometry and a Ph.D. in Biochemistry, all from UAB. He has authored more than 30 publications in the areas of biology, biochemical and X-ray diffraction of visually relevant proteins and microgravity effects on macromolecular crystal growth. He is currently an adjunct professor in materials science at UAB, The University of Alabama in Huntsville, and The University of Alabama in Tuscaloosa and a scientist in the Comprehensive Cancer Center and the Vision Research Center at UAB. DeLucas also serves on the NASA Science Advisory Committee for Advanced Protein Crystal Growth and holds two patents in protein crystal growth.

Payload Specialist (Fluid Dynamics) Eugene H. Trinh [Payload Specialist 2 (PS-2)] is a research scientist at NASA's Jet Propulsion Laboratory. He has a B.S. in mechanical engineering - applied physics from Columbia University and an M.S. and Ph.D. in applied physics from Yale University and has more than 40 research publications. His research has been in the areas of fluid mechanics, materials science and acoustics, and he has studied the behavior of free drops using levitation techniques. He holds six patents for levitation and measurement devices and has more than 20 hours of low-gravity time aboard the NASA KC-135 airplane. Trinh served as co-investigator for the Drop Dynamics Module, an experiment on the Spacelab 3 mission, and was an alternate payload specialist for that flight.



Alternate Payload Specialist (Fluid Dynamics) Joseph M. Prahl is professor of engineering at Case Western Reserve University and a registered professional engineer in Ohio. He earned both a B.A. and a Ph.D. in engineering from Harvard University. He consults for numerous companies and has published more than 20 papers on fluid mechanics, thermodynamics, buoyancy-driven flows, tribology (the study of friction, lubricants, and lubrication), and combustion. Prahl provides research support to NASA Lewis Research Center in absolute ignition delay times, studies in tribology, and on the USML-1 experiments on Surface Tension Driven Convection and Oscillatory Thermocapillary Flow.

Alternate Payload Specialist (Crystal Growth) Albert Sacco, Jr., is head of the Chemical Engineering Department at Worcester Polytechnic Institute. Sacco also serves on the American Institute of Aeronautics and Astronautics Technical Committee on Space Processing. He holds a B.S. in chemical engineering from Northeastern University and a Ph.D. in chemical engineering from the Massachusetts Institute of Technology. He has authored more than 50 publications on carbon filament initiation and growth, catalyst deactivation, and zeolite synthesis and has consulted for several companies in the areas of catalysis, solid/gas contacting and equipment design for space applications. Sacco's expertise enabled him to take part in a joint U.S./European NATO Advanced Study Institute on carbon fibers and filaments.

A Foundation for the Future

While scientists have long theorized about what would occur in an environment free of gravity, it has only been in the last half of this century that research to test these theories has been possible. The microgravity environment of space has allowed the effects of gravity to be stripped away, granting access to phenomena previously impossible to study. As a result, investigators are learning that many processes important for materials and fluid sciences—and our lives—are coupled to gravity in ways that we are just beginning to understand.

The use of microgravity as a tool for science and technology is relatively new. Only since the inauguration of the Space Shuttle/Spacelab system has it been possible to test and improve ideas over several missions. These first steps in an infant research program have allowed scientists and engineers to refine existing procedures and hardware, to design new experiments and facilities, and to begin exploring in new directions.

With USML-1, microgravity research moves firmly toward maturity on Space Station Freedom. Major new instruments, such as the Crystal Growth Furnace, the Drop Physics Module, and the Surface Tension Driven Convection Experiment Apparatus, will be flying for the first time. Concepts for growing zeolite, protein, and semiconductor crystals will be tested; ranges of fluid behavior never before observed will be studied; and astronaut interaction with experiments will reach a new level of sophistication and diversity with the Glovebox. The experiments on USML-1 will contribute significantly to knowledge of basic science and the technology of materials processing. Equally as important as this information are the new avenues identified for future research on Freedom and other advanced platforms.

Every age of human existence has built on the knowledge gained in previous times. The space age is no exception, with each part of NASA's first era of discovery, Mercury, Gemini, Apollo, and the Shuttle, based on all that had come before. NASA's next great era of discovery will rise on the foundation laid by the first. USML-1 is an integral part of this process, and its results will not only link these two eras, but will create a path into the future for microgravity research and commercial applications. ✪

Space Station Freedom

NASA
NASA
esa
US

Co-Investigators

The investigations conducted on USML-1 not only bring together government, academia, and private industry but also teams of scientists who work with the principal investigators in a cooperative effort. These co-investigators are an integral part of all space-based research and help ensure both experiment success and the maximum science return for each investigation.

Experiment	Co-Investigator	Affiliation
Orbital Processing of High Quality CdTe Compound Semiconductors (Crystal Growth Furnace)	Dr. J. Iwan D. Alexander	University of Alabama in Huntsville
	Dr. Gary Bostrup	Rockwell International Science Center
	Dr. Frederick M. Carlson	Clarkson University
	Dr. Donald C. Gillies	NASA/MSFC
	Dr. Daniel F. Jankowski	Arizona State University
	Dr. G. Paul Neitzel	Arizona State University
	Dr. R. R. Neugaonkar	Rockwell International Science Center
	Dr. Bruce Steiner	National Institute of Standards and Technology
	Dr. William R. Wilcox	Clarkson University
Crystal Growth of II-IV Semiconducting Alloys by Directional Solidification (Crystal Growth Furnace)	Dr. Rosalia N. Andrews	University of Alabama in Birmingham
	Dr. Lucia N. Bubulac	Rockwell International Science Center
	Dr. Ching-Hua Su	USRA Visiting Scientist/NASA/MSFC
	Dr. Frank R. Szofran	NASA/MSFC
Study of Dopant Segregation Behavior During Growth of GaAs in Microgravity (Crystal Growth Furnace)	Mr. James Kafalas	NASA Consultant
	Dr. Shayhar Motakef	Massachusetts Institute of Technology
Surface Tension Driven Convection Experiment (Surface Tension Driven Convection Exp. Apparatus)	Dr. Yasuhiro Kamotani	Case Western Reserve University
Drop Dynamics Experiment (Drop Physics Module)	Dr. Martin Barmatz	NASA/JPL
	Dr. Eugene H. Trinh	NASA/JPL
Science and Technology of Surface Controlled Phenomena (Drop Physics Module)	Dr. Dan Elleman	NASA/JPL (deceased)
	Dr. R. Glynn Holt	Yale University
Measurement of Liquid-Liquid Interfacial Tension (Drop Physics Module)	Dr. George F. Neilson	University of Arizona
	Dr. R. Shankar Subramanian	Clarkson University
	Dr. Eugene H. Trinh	NASA/JPL
Astroculture™	Dr. Raymond J. Bula	Wisconsin Center for Space Automation & Robotics
	Mr. William R. Dinauer	Wisconsin Center for Space Automation & Robotics
	Dr. Neil Duffie	Wisconsin Center for Space Automation & Robotics
	Dr. Robert C. Morrow	Wisconsin Center for Space Automation & Robotics
Generic Bioprocessing Apparatus	Dr. Marvin W. Luttges	University of Colorado
	Dr. Steve Simske	University of Colorado
	Dr. Louis Stodieck	University of Colorado
Protein Crystal Growth	Dr. Shigeo Aibara	Kyoto University, Japan
	Dr. Wayne F. Anderson	Vanderbilt University
	Dr. Y. S. Babu	BioCryst, Inc.
	Dr. George I. Birnbaum	National Research Council of Canada
	Dr. Charles William Carter, Jr.	University of North Carolina
	Dr. Daniel Carter	NASA/MSFC
	Dr. William J. Cook	University of Alabama at Birmingham
	Dr. Edmund Czerwinski	University of Texas Medical Branch
	Dr. Larry J. DeLucas	University of Alabama at Birmingham
	Professor Guy G. Dodson	University of York, England
	Dr. Jan Drenth	University of Groningen, The Netherlands
	Dr. David J. Duchamp	The Upjohn Company
	Dr. Steven E. Ealick	University of Alabama at Birmingham
	Dr. Drake S. Eggleston	Smith, Kline & French Laboratories
	Dr. Howard M. Einspahr	The Upjohn Company
	Dr. Gregory K. Farber	Pennsylvania State University
	Dr. Barry C. Finzel	The Upjohn Company
	Dr. Juan Fontecilla Camps	Laboratoire de Cristallographie de Macromoles Biologiques, France
	Dr. Arthur Frankel	Florida Hospital Cancer & Leukemia Research Center
	Dr. Noel Jones	Eli Lilly & Company
	Dr. Yesook Kim	Eli Lilly & Company
	Dr. A. Kossiakoff	Genentech, Inc.
	Dr. James R. Knox	University of Connecticut
	Dr. Thomas A. Krenitsky	Burroughs-Wellcome Company
	Dr. W. Graeme Laver	The Australian National University, Australia
	Dr. Ponzy Lu	University of Pennsylvania
	Dr. Alexander McPherson	University of California, Riverside
	Dr. Edward J. Meehan	University of Alabama in Huntsville
	Dr. Edgar F. Meyer	Texas A&M University
	Dr. T. L. Nagabhushan	Schering Corporation
	Dr. Robert J. Naumann	University of Alabama in Huntsville
	Dr. Manuel Navia	Vertex Pharmaceutical
	Dr. P. G. Righetti	University of Milan, Italy
	Dr. William M. Rosenblum	University of Alabama at Birmingham
	Dr. Byron H. Rubin	Eastman Kodak Company
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	Dr. Vijay-Kumar Senadhi	University of Alabama at Birmingham
	Dr. Larry Sieker	University of Washington
	Dr. Paul B. Sigler	Yale University
	Dr. Robert S. Snyder	NASA/MSFC
	Dr. Fred L. Suddath	Georgia Institute of Technology
	Dr. M. Sundaralingam	Ohio State University
	Dr. Robert M. Sweet	Brookhaven National Laboratory
	Dr. Paul Trotta	Schering Corporation
	Dr. Donald Voet	University of Pennsylvania
	Dr. Keith Ward	Naval Research Laboratory
	Dr. Keith D. Watenpaugh	The Upjohn Company
	Dr. Patricia Weber	DuPont Merk Pharmaceutical Company
	Dr. Ada Yonath	DESY/MPG, Germany
Zeolite Crystal Growth	Dr. Anthony G. Dixon	Worcester Polytechnic Institute
	Dr. Robert W. Thompson	Worcester Polytechnic Institute

Glovebox Co-Experimenters

Just as the major experiments on USML-1 have other investigators working with the principal investigators, so do the experiments conducted in the Glovebox. These co-experimenters are also an integral part of the research being conducted on the mission and help ensure the maximum scientific return.

Experiment	Co-Investigator	Affiliation
Passive Accelerometer System	Dr. Charles R. Baugher Dr. Robert J. Naumann	NASA/MSFC University of Alabama in Huntsville
Interfacial Configuration Experiment	Dr. Robert Finn Mr. Mark M. Weislogel	Stanford University NASA/LeRC
Solid Surface Wetting Experiment	Mr. John Depew	NASA/JPL
Smoldering Combustion in Microgravity	Ms. Sandra L. Olson Mr. Dennis P. Stocker	NASA/LeRC NASA/LeRC
Wire Insulation Flammability Experiment	Dr. Takashi Kashiwagi Mr. Kurt R. Sacksteder	National Institute of Standards and Technology NASA/LeRC
Nucleation of Crystals from Solutions in a Low-g Environment	Dr. Sandor L. Lehoczky Dr. Donald A. Reiss	NASA/MSFC NASA/MSFC
Oscillatory Dynamics of Single Bubbles	Dr. Eugene H. Trinh Mr. John Depew	NASA/JPL NASA/JPL
Oscillatory Thermocapillary Flow	Dr. Yasuhiro Kamotani Mr. Alexander D. Pline	Case Western Reserve University NASA/LeRC
Candle Flames in Microgravity	Dr. Daniel L. Dietrich Dr. James S. T'ien	Sverdrup Case Western Reserve University
Fiber Pulling in Microgravity	Dr. Bonnie Dunbar Dr. David Nover	NASA/JSC NASA/MSFC
Stability of a Double Float Zone	Dr. Narayana Ramachandran	USRA
Directed Orientation of Polymerizing Collagen Fibers	Dr. Todd Bergren Dr. Marvin W. Luttges Dr. Michael C. Robinson	University of Colorado University of Colorado University of Colorado

Hardware Developers

Much of the attention of the media and public to any mission is focused on the scientific experiments being performed. Just as important to the success of a mission as the scientists are the hardware development teams that develop the equipment needed to perform the various investigations. Often overlooked, these groups of NASA and private industry personnel work tirelessly to convert ideas into mechanical reality and deserve recognition for their contributions to mission success.

Facility	Project Manager	Location
Crystal Growth Furnace	Mr. David A. Schaefer	NASA/MSFC
Surface Tension Driven Convection Experiment Apparatus	Mr. Thomas P. Jacobson	NASA/LeRC
Drop Physics Module	Mr. Joe A. Hanson	NASA/JPL
Astroculture™ Facility	Dr. Robert Morrow	Wisconsin Center for Space Automation & Robotics
Generic Bioprocessing Apparatus	Dr. Michael C. Robinson	Center for Bioserve Space Technologies, University of Colorado
Extended Duration Orbiter Medical Program	Mr. J. Travis Brown	NASA/JSC
Protein Crystal Growth Apparatus	Mr. Ronald C. Darty	NASA/MSFC
Space Acceleration Measurement System	Mr. Richard DeLombard	NASA/LeRC
Solid Surface Combustion Experiment Apparatus	Mr. John M. Koudelka	NASA/LeRC
Zeolite Crystal Growth Facility	Ms. Lisa A. McCauley	Battelle Advanced Materials Center for the Commercial Development of Space
Glovebox	Mr. Roger P. Chassay	NASA/MSFC

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