INFORMATION SYSTEMS REQUIREMENTS FOR THE MICROGRAVITY SCIENCE AND APPLICATIONS PROGRAM

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Abstract

This paper briefly discusses NASA's Microgravity Science and Applications Division (MSAD) Program, the types of information produced within the program, and the anticipated growth in information system requirements as the program transitions to Space Station Freedom utilization. Plans for payload operations support in the Freedom era will be addressed, as well as current activities to define research community requirements for data and sample archives.

I. Introduction

NASA's Microgravity Science and Applications Division sponsors basic and applied scientific investigations requiring reduced or near-zero gravity conditions. The reduction of gravity-induced phenomena, including buoyancy-driven convection, sedimentation, and hydrostatic pressure in experiments conducted in space provides a unique opportunity to obtain valuable insights into a variety of physical processes and materials. The sustained reduced-gravity environment provided by Shuttle and planned for Space Station Freedom allows researchers the opportunity to conduct extensive investigations under these favorable conditions.

The areas of research and development supported by the MSAD encompass 1) fundamental science, which includes the study of the behavior of fluids, transport phenomena, condensed matter physics and combustion science; 2) materials science, which includes electronic and photonic materials, metals, alloys, glasses and ceramics; and 3) biotechnology, which focuses on macromolecular crystal growth and cell science. Knowledge gained from experiments conducted in space improves our understanding of basic scientific principles and phenomena, which can provide important contributions to Earth-based technology. This increased understanding may, in turn, lead to productivity gains in manufacturing processes, and the development of new and improved materials and pharmaceuticals. Contributions such as these support the United States' ability to remain a world leader and to be competitive in the world economy.

The Microgravity Science and Applications Program consists of two major parts; the ground-based research and analysis program, and the flight program. Transition to flight experiment status occurs after the hypothesis to be tested in space is clearly defined and ground-based research and testing demonstrates sufficient technical maturity to assure that science objectives can be met in space with a high probability of success.

The program strategy calls for a transition to the Space Station Freedom before the end of the century. Up to six multi-user facilities are planned to be phased into operation aboard Space Station over an extended timeframe. The design of these facilities will evolve based on experience with precursor experiment hardware designed and operated on the Space Transportation System (STS) "Spacelab" and other carriers.

While the current program strategy emphasizes the use of STS and transition to Space Station Freedom, the strategy does not preclude using other available carriers. The use of additional carriers, such as sounding rockets and free-flying spacecraft, is being investigated; the key goal being to assure a well-rounded program that remains affordable and satisfies the requirements of a diverse scientific community.

II. Current Data Products and Information Systems

As indicated in the introduction, the Microgravity Science and Applications Division supports several scientific disciplines, each of which has unique processing requirements and data and/or sample products. Representative research disciplines and their corresponding data products include:

Protein Crystal Growth Research: The biological functions of protein macromolecules are determined by their three-dimensional molecular structures. Given an understanding of how molecules function, one can find methods for altering or controlling molecular function. At present, the main method available for determining molecular structure is through x-ray diffraction data obtained from crystals of the material. The array of molecules in the crystalline lattice diffracts x-rays, which form a distinctive pattern that can be captured with film or electronic area detectors. Subsequent computer analysis allows researchers to convert the patterns into electron density maps, from which molecular structure can be deduced.

The primary goal for growing protein crystals in space is to eliminate problems caused by sedimentation and buoyancy driven convection, in an effort to produce larger, more uniform crystals. These will diffract to a greater resolution, thereby allowing for more accurate molecular structure determination.

In addition to the actual samples produced on orbit and the corresponding ground-based results of x-ray diffraction analysis, typical data products produced for current protein crystal growth experiments in space include chronological thermal histories of the growth environments and time-lapse photography of the growth chambers.

Electronic Materials Research: Semiconducting materials play a key role in our modern technology. Key to the development of solid state electronics is 1) the ability to produce very pure and well-ordered single crystalline solids from elements and compounds that have semiconducting properties, and 2) the ability to introduce precisely controlled trace quantities of dopants that determine the material's electrical properties. Strong magnetic fields are used to reduce

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convective flows in large melts. However, not even the strongest magnetic fields can reduce buoyancy-driven convective flows sufficiently to achieve diffusive transport in large melts when under Earth's gravity.

Newer materials based on Group III-V or Group II-VI compounds or alloys of these elements have unique properties that cannot be obtained from elemental semiconductors. They have higher electron mobilities, which means they can switch or process information faster. They also have more tolerance to hostile thermal and radiation environments. However, the presence of multiple components adds another dimension of control that is required on composition of the material. The crystalline lattice of many such materials tends to be soft, and large crystals may actually deform under their own weight during solidification. Experiments in microgravity help clarify the role of convection in control of composition and defect formation, as well as the role of container walls and hydrostatic pressure in formation of dislocations.

Data products in this discipline include chronological histories of the sample's thermal environment and its position relative to the furnace, as well as time-lapse photography for vapor diffusion processes. Additionally, NASA is supporting advanced technology development of gamma and X-ray techniques to measure and record the position and shape of a melt's liquid-solid interface during liquid diffusion processes.

Metals and Alloys: Most of the metals and alloys used today are cast from the melt. The solidification in a casting process is even more complex than the growth of single crystals, though usually not as well controlled. Useful alloys often have multiple components, each of which has a different freezing temperature. In addition to the segregation effects of these components, multiphase reactions can occur when a liquid transforms into two distinct solids (eutectic reaction), into a solid and a second liquid (peritectic reaction), or into two immiscible liquids (monotectic reaction). Invariably these multiple phases have different densities which cause macrosegregation (variations in compositions over the bulk). Some of the earlier microgravity experiments revealed the influence of strong interfacial effects which also play a major role in phase separation.

Data requirements in this discipline are very similar to those identified for electronic materials. In addition to the actual samples produced on orbit and the corresponding ground-based analysis results, chronological thermal histories of the growth processes are retained, as well as histories of the sample's position relative to the furnace. As with the electronic materials discipline, NASA will apply its advanced technology development of gamma and X-ray techniques to measure and record the position and shape of a melt's liquid-solid interface during the solidification process.

Fluids and Transport: The vast reduction in density-driven convection provided by the microgravity environment allows the study of other forms of convection such as flows driven by electrohydrodynamics, surface tension gradients, or other interfacial phenomena. Not only are such flows interesting in their own right, but they must be understood and controlled in space experiments. Transport is vastly simplified in the absence of convective flows. This allows many processes involving heat flow or mass transport to be analyzed and the relative contributions from diffusion and convection to be identified.

Experiments in space are conducted to help understand and model flows caused by surface tension and free surface phenomena, to study the growth of dendrites as materials solidify from an undercooled melt, to investigate nucleate pool boiling in microgravity, and to examine bubble/droplet dynamics and interactions.

Fluids and Transport experiments typically require extensive temperature field maps and very precise temperature control (to within 0.002 K). They rely heavily on the use of film systems (usually with multiple fields of view) to observe bubble nucleation, growth, motion and collapse; and to record free surface shape and motion, the velocity distribution of tracer particles along the free surfaces, and transient and steady-state flow behavior.

Combustion: Because combustion processes involve the release of chemical energy, which results in steep thermal gradients, buoyancy driven convection plays a major role in transport of heat and chemical species in Earth gravity. Microgravity significantly reduces this convective transport which enables researchers to study the combustion process under vastly simplified conditions. In addition to obtaining fundamental knowledge, combustion research also addresses aspects of spacecraft fire safety and how to deal with potential fires.

Typical experiments involve investigation of processes and phenomena related to burning of solid, liquid, and gaseous fuels in a variety of environments. The study of combustible particle clouds is of fundamental scientific interest as well as practical concern. Such clouds spread fires in underground mining operations and contribute to the fire and explosion hazards of grain storage and handling facilities. Experiments have been designed to examine solid surface, particle cloud and droplet combustion.

Combustion researchers rely heavily on the use of film systems to provide information on droplet and flame diameters as a function of time, flame shapes, color and luminosity, and flame propagation modes and rates. Species concentration measurements are recorded, and temperature measurements of fuel surfaces and gas phases are taken to provide information on radiant heat flux from the fuel surface and heat conduction in solid and vapor phases.

Acceleration Environment Characterization and Analysis: Of key concern to microgravity science and applications researchers is the nature of the acceleration environment on-orbit. To better understand and exploit the orbital environment effectively, the Microgravity Science and Applications Division supports analytical research to derive experiment acceleration requirements, and is developing methods and hardware to characterize the actual acceleration environment on microgravity experiment carriers.

The Space Acceleration Measurement System (SAMS), developed by Lewis Research Center for the Microgravity Science and Applications Division, will fly for the first time on the Spacelab Life Sciences-1 mission. SAMS will fly on all long module Spacelab flights and other Shuttle flights with microgravity payloads. SAMS units have been developed to support experiments inside the pressurized Shuttle compartments (middeck and Spacelab) or in the cargo bay. Each unit is designed to measure, condition and record low-level accelerations (i.e. on the order of 10^{-6}g at .1 Hz) at up to three different experiment sites simultaneously.

The Division recently initiated the "Acceleration Characterization and Analysis Project" (ACAP) to help investigators better understand experiment carrier acceleration environments. The ACAP will provide summary reports of the acceleration environment of all Shuttle missions supporting microgravity experiments; it will provide yearly reports summarizing the progress to date in understanding the acceleration environment of the Shuttle and other carriers that may have flown with accelerometers and microgravity payloads; and it will provide special reports to support individual investigator requirements and to investigate topics of concern relative to the acceleration environment.

Current Information Sets and Databases: Currently, the data and corresponding information derived from a given investigator's experimental efforts reside at the investigator's home institution. Flight samples not destroyed through characterization analysis remain the property of NASA but are typically retained by the investigators for continuing analysis. Flight investigators are required to provide the MSAD an interim report at six months and a final report summarizing the results of their analysis one year after flight of their experiments.

The MSAD strongly encourages all investigators to regularly publish their progress in appropriate scientific journals. The Division publishes, on a yearly basis, the Microgravity Science and Applications Bibliography, which provides a comprehensive compilation of government reports, contractor reports, conference and symposia proceedings, and journal articles dealing with flight experiments utilizing a low-gravity environment to elucidate and control various processes, and with ground-based activities that provide supporting research. All papers are retained on file and copies can be made available to workers in the field on request to the bibliographer (Universities Space Research Association).

The Division supports the continued development of a database documenting over 700 fluids and materials processing experiments performed in space. The missions encompassed within the database include Mercury, Apollo, Skylab, Apollo-Soyuz, Soyuz-Salyut, the U.S. Shuttle Program and domestic and international sounding rocket programs. The database, developed by Ms. Cheryl Winter, resides at the Marshall Space Flight Center. Each entry provides a brief synopsis of the experiment, identifies the principal and co-investigators, specifies on which mission the investigation was flown, lists relevant publications, and identifies a point of contact for obtaining further information. One of the goals of the Division is to make this information easily accessible to the interested researchers.

Also supported by the Division is the Microgravity Science Applications Management System (MSAMS) Network. This is a custom designed multi-user, on-line (telephone modem) repository for information relative to 1) resource requirements for planned MSAD Space Station experiment facilities, 2) resource requirements for Shuttle "precursor" flight hardware, and 3) principal investigators within the program.

III. Information System Requirements in the Space Station Era

NASA's Microgravity Science and Applications Program is a relatively young program, and as such has had only limited flight experience. The total number of MSA experiment flight hours is less than 1800, and a significant portion of these are the result of early hand-held experiments. However, upcoming United States Microgravity Laboratory (USML) and International Microgravity Laboratory (IML) Spacelab series, and United States Microgravity Payload (USMP) cargo bay series will provide a number of Shuttle opportunities for dedicated microgravity research in advance of Space Station Freedom.

An orderly, affordable evolution into the Space Station Freedom era is planned. Experimental research will transition to flight experiment status only after ground-based research clearly defines the hypothesis to be tested, and testing demonstrates sufficient technical maturity to assure science objectives can be met in space with a high probability of success. The design of Space Station experimental facilities will evolve based on experience with precursor experiment hardware designed and operated on the Shuttle Spacelab and other carriers.

Efficient utilization of Space Station Freedom will require facility-class hardware that is flexible enough to accommodate a wide variety of experiments. In order to remain state-of-the-art, experiment facilities must be able to accommodate new technologies and experiment concepts as they are developed. To maintain this flexibility, a modular approach is being used where elements of the facility may be changed on orbit as new experiment requirements and/or technologies are identified and developed.

This evolutionary approach allows the microgravity science community to take advantage of near-term Shuttle research opportunities, provides hardware developers an opportunity to refine experiment design concepts before committing them to long-term flight aboard the Space Station Freedom, and allows experiment facilities on Freedom to accommodate advances in research and technology as they become available.

The Microgravity Science and Applications Division is currently defining requirements and developing conceptual designs for six multiuser facilities for deployment aboard Space Station Freedom. The Space Station Furnace Facility (SSFF) will support a collection of furnaces for growing high-quality semiconductor crystals, for solidifying various alloys and composites, and for measuring thermophysical properties of metals and alloys. The Modular Containerless Processing Facility (MCPF) will accommodate a variety of experiments that require the positioning and manipulation of samples without physical contact. Acoustic, electro-magnetic, and electrostatic fields will provide the forces required to manipulate the sample and to overcome residual spacecraft accelerations. The Advanced Protein Crystal Growth Facility (APCGF) will incorporate new technology under development in our ground-based research programs to sense and control nucleation and growth of protein crystals. The Fluid Physics/Dynamics Facility (FP/DF) will accommodate a variety of experiments in fluid flow and transport phenomena. The Modular Combustion Facility (MCF) will provide suitable containment and diagnostics to study combustion phenomena in microgravity. Finally, the Biotechnology Facility (BTF) will consist of one or more bioreactors and associated equipment for supporting cell science investigations.

Information generated by microgravity science and applications researchers in the Space Station era is expected to be of a nature similar to that generated as a result of today's programs. However, the amount of information generated is expected to increase significantly, given the anticipated increase in flight experiment opportunities afforded by Space Station. Additionally, methods for obtaining the information are expected to change.

Today, microgravity science and applications researchers rely heavily on film systems to provide inflight experiment observation. The logistics burden for film is high, but with the relatively short duration of Shuttle missions, the burden is acceptable. Given longer duration Space Station increments (the periods between Shuttle visits), the logistics burden that film systems impose becomes too great. Another inherent problem with use of film is that it does not allow researchers on the ground the option to remotely control experiments (in realtime or near realtime) based on downlinked observations. As a result, researchers using Space Station are expected to rely more heavily on video and digital imagery systems. Therefore, the MSAD has placed an emphasis on evaluating and presenting to the Space Station Freedom Program Office requirements for on-board data transfer, storage, processing and downlink; and it is currently evaluating options for improving MSAD program approaches to information archival.

IV. Payload Operations Support in the Space Station Era

Space Station Freedom will require the continuous operation of approximately ten times the number of experiment racks currently operated on Spacelab, with less than twice as many crew members. The actual science users will be numerous and widely distributed, and it may be impractical to transport them in large numbers to a centralized operations location throughout the long lifetime of the Freedom program. The normal day-to-day science operations will involve continuous and often simultaneous real-time replanning; real-time and near real-time experiment control; and ongoing science data management, distribution, and archiving. Experiments themselves will become increasingly complex and sophisticated. The principal investigators will require greater interaction with on-orbit scientists, as well as with their own ground-based investigator teams operating from home laboratories.

The effective integration of the operations of all science users on a continuous and routine basis represents a challenge that differs significantly from the current operational concepts for the Spacelab and Shuttle systems. Within NASA's Office of Space Science and Applications (OSSA), plans are underway to develop an Integrated Science Operations Center which will initially support centralized science operations for all science users; OSSA's long-term goal being to conduct flight operations from distributed Discipline Operations Centers (DOCs), with experimenters at DOCs or at their home institutions. The Microgravity Science and Applications Program approach is consistent with the OSSA concept: its operations center development efforts will be evolutionary, beginning with a centralized operations capability located at the Marshall Space Flight Center. The numbers of operations centers, their capabilities, and their distribution among user sites will increase over time based on science and budget priorities.

Control and Monitoring: For many microgravity experiments, having a person in the loop improves the probability of experiment success and enhances scientific return. Depending on the activity, this person may be either a crew member or an investigator on the ground. Given anticipated crewtime limitations in the Space Station era, there will be a significantly greater need for ground-based experimenters to participate in the inflight experiment while it's being conducted. Typically, the control and monitoring function will be accomplished by transmitting to the ground a data stream consisting of the minimum amount of data needed by the investigator to make adjustments to his or her experiment. Data streams will consist of experiment or instrument digital data, acceleration data, visual and audio data. Depending on the facility being used, visual data will consist of station-provided video or high-resolution/high-frame rate digital imagery. Given the large amounts of data anticipated from experiments on Space Station, both experiment equipment and Station will require designs which enhance the ability to efficiently transfer, store, process and downlink data.

V. Requirements for Data and Sample Archives

The MSAD sponsored a workshop at the National Space Science Data Center (NSSDC) at Goddard Space Flight Center in July of this year. The purpose of the workshop was to evaluate current and projected data management requirements for the Microgravity Research Community and to develop recommendations for future data management, distribution, and archival. Workshop attendance included investigators and other appropriate representatives from each of the Microgravity Science and Applications research disciplines.

In general, the workshop participants felt that, although the need to archive data exists, the archival requirements of the microgravity science community are small when compared to the requirements of other research communities (the observing sciences, for example). A substantial amount of the data generated on-orbit can be condensed via data compression and other techniques to significantly reduce both downlinking and archival requirements. The archives should retain complete histories of the experiments, including both ground-based and flight results and calibration data. Workshop participants felt that archiving requirements and the archives themselves should be addressed and developed on a discipline by discipline basis, with emphasis placed on discipline archive interoperability. The Division also needs to refine current procedures for sample handling, storage and access.

As a result of the workshop, the Division developed a list of recommendations concerning the establishment of Microgravity Science and Applications data archives and policy needed relative to data management. These recommendations are currently under review by the Division's science Discipline Working Groups. After this review, a final set of recommendations will be agreed upon and a program to implement them will be developed.

VI. Summary

NASA's Microgravity Science and Applications Program utilizes the unique characteristics of the space environment, primarily the near absence of gravity, to expand man's knowledge of the fundamental sciences, materials sciences and biotechnology, and to demonstrate the feasibility of space production of improved materials that have high technological utility. The potential rewards of the program include a better understanding of the physical processes in our environment, which may lead to refined control strategies; and advancements in technology, which may lead to important commercial applications.

NASA has an aggressive space flight program planned for the microgravity science and applications research community, with numerous Shuttle opportunities and a transition to the international Space Station Freedom planned for the 1990's. The amounts of data generated in the Space Station era are expected to increase dramatically, and as a result, new approaches to data capture, transfer, storage, processing, and archival must be addressed. New methods must be developed to support on-orbit operations and facilitate remote monitoring and control of experiments. The Microgravity Science and Applications Division looks forward to working with its research community to develop the information systems infrastructure required to ensure a successful transition to Freedom.

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