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PREPARATION FOR MICROGRAVITY: THE ROLE OF THE MICROGRAVITY MATERIALS SCIENCE LABORATORY

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NASA has established at the NASA Lewis Research Center a laboratory dedicated to ground based materials processing in preparation for space flight. Experiments are performed to delineate the effects of gravity on processes of both scientific and commercial interest. Processes are modeled physically and mathematically. Transparent model systems are used where possible to visually track convection, settling, crystal growth, phase separation, agglomeration, vapor transport, diffusive flow, and polymers reactions. The laboratory contains apparatus which functionally duplicate apparatus available for flight experiments and other pieces instrumented specifically to allow process characterization. Materials addressed include metals, alloys, salts, glasses, ceramics, and polymers. The Microgravity Materials Science Laboratory is staffed by engineers and technicians from a variety of disciplines and is open to users from industry and academia as well as the government. Examples will be given of the laboratory apparatus, typical experiments, and results.

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The commercialization of space started in the 1960's with the first of the communications satellites. The second wave of commercialization began with the availability of the space shuttle, when access to space became easier. It will be further enhanced by the availability of long term laboratories in space. These laboratories, whether commercial or government run, will provide a unique environment for all kinds of projects, many with commercial potential. Aside from the obvious utilization of these space platforms as vantage points for viewing the earth and space, they will also be useful for processes which require freedom from gravity. They will be able to provide the extended periods of microgravity that may be needed for commercial production.

Before a commercial organization can make good use of the microgravity environment of space, a careful analysis must be done of the way gravity interacts with the process of interest. When its effects are generally understood, the decision to design specific experiments and build experimental hardware can be made.

One problem with evaluating a research idea in an unfamiliar area is the necessity to develop expertise before making the evaluation. The development of this expertise requires that the researcher do experiments. Conducting experiments requires the construction of facilities and equipment. All of these conspire to significantly raise the costs and therefore the risk. The enhanced risk - the specter of spending a lot of money in order to learn that the experiment is not worth spending money on - often causes potentially promising ideas to go unexplored. This is especially critical to businesses which are relatively small and do not have the resources for an extensive R&D program. They are left with a pair of bad choices - to risk money on speculative R&D that may not pay off or to risk that a competitor may find and exploit an important process that could have been uncovered with a reasonable R&D effort.

In order to lower the risk of microgravity materials science experimentation NASA opened the Microgravity Materials Science Laboratory (MMSL) at the NASA Lewis in September 1985. This laboratory is a place where a person with an idea for a microgravity experiment can investigate the viability of the idea without incurring large costs.

Because of the high costs and relative scarcity of space flight opportunities, it is imperative that experiments be well characterized on the ground before they are flown. Characterization should begin at the conceptual stage to insure that the experiment is worthwhile and will produce the expected results. After the viability of the concept is determined, preliminary experimentation should be done in order to determine the feasibility of the proposed experiment and to serve as a guide in the identification and design of flight hardware. Only after the experiment is designed and the concepts proven on the ground should the construction of flight hardware begin.

The MMSL provides a unique environment for all stages in the development of a ground-based microgravity experiment. As is illustrated in figure 1, the experimenter begins by contacting the laboratory staff for preliminary discussion of the experimental idea. When a viable experiment is identified, the experimenter can make an informal proposal through the laboratory manager for use of the facilities. If the necessary facilities are available, the experimenter can use the lab to develop an experimental approach that may be carried through to a flight experiment.

Usage fees are determined by the type of research performed. If the experimenter agrees to publish the results of the work done in the MMSL in the open literature within two years of completion of the experiment, there is no charge for the use of the laboratory. If the results are proprietary, a user fee will be negotiated before the project begins. The user fee serves to repay the government for the real expenses incurred in supporting proprietary work. In any case, the housing, salary, and per diem expenses of the visiting experimenters will be the responsibility of the experimenter's home institution.

Two things make the MMSL an attractive place to do preliminary work on a microgravity materials science idea. The first is the staff. The MMSL's relatively small staff of scientists and engineers have a wide range of expertise. Chemistry, physics, and metallurgy are represented as well as mechanical, electrical, nuclear, and welding engineering. Because the staff is relatively small there is a great amount of interdisciplinary overlap, and a teamwork oriented approach is taken to most problems. Also, since the MMSL is a part of the 180+ person NASA Lewis Materials Division the extensive knowledge and experience of this organization is also available.

The second feature making the MMSL a good place to develop a new idea is the equipment available. The MMSL is divided into three smaller laboratories, specializing in metals and crystal growth, ceramics and glasses, and polymers. These laboratories are equipped with the instrumentation appropriate for their discipline.

The metals and crystal growth lab was the first part of the MMSL to begin operation. It contains several broad types of experimental equipment: functional duplicates, which emulate the function and major characteristics of a flight experiment; conceptual duplicates, which use the same processes as flight equipment but have operating capabilities tailored to ground based use; and experiment models, which are not necessarily designed to model specific flight experiments but are generally used for generating 1-g baseline data.

The major functional duplicate in the metals and crystal growth lab has been the General Purpose Furnace (GPF). This apparatus, a three zone resistively heated furnace, duplicates one third of the space shuttle flight version of the GPF. The MMSL's GPF is more heavily instrumented than the flight version, with nine thermocouples available for monitoring the walls and heater bands and up to twelve thermocouples in the sample canister. This temperature measurement system allows for complete characterization of the combined furnace/sample system and eases the development and preflight checkout of temperature profiles. In this way the GPF provides an important service to experimenters contemplating the use of the flight version of the GPF.

The flight version of the GPF has been retired and is being replaced with a more modern design based on the experience gained from previous experiments. As flight furnaces improve, the MMSL's GPF apparatus will be reworked to track these changes in order to provide the best possible preparation for future flight experiments. A plan to redesign and reprogram the current GPF in order to allow its use for directional solidification experiments is currently being developed.

An Advanced Technology Development project concerning the design of improved furnaces is currently underway. This work complements the work done on the MMSL furnaces and will result in shaping the next generation of small flight furnaces.

The second piece of flight duplicate hardware in the metals and alloys section of the MMSL is the isothermal dendrite growth apparatus. This apparatus, which allows for tracking and observation of the growth of dendrites in succinonitrile, was designed as a precursor to the flight version of the same experiment. Succinonitrile was chosen for this experiment because it solidifies dendritically (as do metals) but is transparent in both its liquid and solid states. Dendritic solidification involves the crystallization of a molten material into "christmas tree"-like structures.

The apparatus allows observation of the growth of a single free dendrite into an undercooled melt. The temperature of the system is regulated to within 0.001 °C, and the growing dendrite tracked with a microscope. Using film and video to record the image of the growing dendrite, both the tip radius and growth rate can be measured. Dendrite growth under these conditions is adversely affected by the presence of gravity as density driven convection in the fluid near the growing dendrite tip can distort the shape and change the growth rate. The distortion occurs as the heat of fusion is released into the surrounding liquid, warming it and causing it to flow. The convective flow has two effects: the upper portion of the dendrite is surrounded with warm liquid, inhibiting its growth; the bottom is surrounded with cool liquid, enhancing growth. This distorts the dendrite, making the measurements difficult. In the micro G environment, flow should be minimized, making measurements easier and more accurate.

The laboratory's conceptual duplicates include the electromagnetic levitator/instrumented drop tube. This apparatus is composed of a high power, radio frequency generator energizing a coil contained in a large vacuum chamber. The coil, shaped like an inverted cone with the bottom open, produces a strong vertical ac magnetic field. An opposing wrap at the top completes a magnetic field trap. A conductive sample in the trap experiences induced eddy currents opposing the trap field. The magnetic field produced by the eddy currents provides a repulsive force, causing the sample to levitate within the coil. The eddy currents also cause resistive heating in the sample. As a result, the levitation and heating mechanisms are coupled. Figure 2 shows a view into the EML vacuum chamber showing the coil and sample manipulation device.

While the EML provides true levitation and allows heating without contact with a container, the act of levitation induces strong stirring within the sample. The only "clean" microgravity environment available within the MMSL is found in the one second Instrumented Drop Tube (IDT). This device, situated below the EML vacuum chamber is a 5-m drop tube capable of being evacuated and held in the low 10^{-6} torr range. A number of two color pyrometers allow continuous, high speed temperature measurement during the drop. The IDT is usable with nearly any sample that can be levitated in the EML as long as solidification during the drop is not necessary. If solidification in microgravity conditions is required, only small samples can be dropped. The EML/IDT system is currently being modified to allow for the handling of extremely small samples (down to 0.1 mm).

Another conceptual duplicate is the high temperature directional solidification furnace (fig. 3). This furnace, capable of operation to 1100 °C, provides the MMSL with the capability of directionally solidifying relatively large samples (approximately 100 g). In this experiment, the low-convection environment of a space experiment can be approached through the use of magnetic damping. A moderate size magnetic field (ca. 5 K Gauss) is used to break up large convection cells in electrically conductive melts.

The largest group of MMSL experiments are those used to model processes or develop 1-g baseline data. These investigations probe areas of interest to materials scientists working with microgravity experiments, but are neither functional or conceptual duplicates of existing equipment.

The crystal growth furnace is an example of such an experiment. This furnace consists of a transparent quartz tube wrapped with heater wire to form a four-zone furnace. The sample is encapsulated in a quartz ampoule and suspended in the furnace with a wire. The wire is a part of a motion assembly which allows the sample to be moved within the furnace at rates as low as 50 nm/sec. Axial temperature gradients can be varied from 0 to 40 °C per centimeter, and the furnace is wired in a manner that allows independent temperature control across zones. This arrangement allows the axial temperature profile to be controlled. Several compounds have been processed using this equipment, including Lead Chloride (grown from the melt) and Mercurous Chloride (grown by physical vapor transport).

The behavior of undercooled metal alloys has been examined in the Bulk Undercooling Furnace, a three zone resistively heated furnace with a capacity of up to 100 g. Careful temperature control is used to obtain significant undercooling. The knowledge gained through the use of this instrument will provide guidelines for the design of space experiments.

Combining a study of dendritic growth with directional solidification, the Transparent Directional Solidification Furnace makes use of succinonitrile to allow observation of phenomena which would be difficult to observe in a metal sample. In this experiment, the molten succinonitrile sample is observed while it is directionally solidified using a moving furnace. The design of the furnace allows the growth zone to be lighted and observed from either the side or the top.

The recently opened ceramics lab includes all of the equipment necessary to compound and characterize ceramics and glasses including a number of furnaces, thermal analysis equipment, and viscosity measurement instruments. This laboratory houses another functional duplicate of a piece of flight hardware, the Single Axis Acoustic Levitator (SAAL). This levitator uses a high frequency (15 kHz) acoustic generator and a reflector to provide an acoustical standing wave. Small samples (up to 6 mm) can be suspended in the nodes of this sound wave and heated using the surrounding furnace which is capable of reaching temperatures of up to 1600 °C.

While useful for suspending and heating materials which are not conductive enough to be levitated electromagnetically, acoustic levitation has some major drawbacks when used in a 1-g environment. At a pressure of 1 atm. the acoustic field generated by the levitator is not powerful enough to support objects with a density of more than about 0.3 g/ml. This severely limits the utility of the device for ground based processing of interesting materials. While designs for more useful acoustic levitators are being developed, the SAAL's major utility comes in the evaluation of the positioning properties of the acoustic field using a mechanically suspended sample, and from its high temperature (1600 °C) furnace.

The MMSL's polymers laboratory has recently been completed. The laboratory houses, along with "standard" analytical instrumentation - Fourier Transform Infrared Spectrometer, thermal analysis equipment, porosimeter, dilatometer, and rheology apparatus - the laboratory's Laser Light Scattering Instrument. This instrument is useful for studying particle size distribution in solution as well as the shapes of molecules. It also forms the basis of the Laser Light Scattering Advanced Technology Development effort in the MMSL. This effort is a preliminary investigation aimed at the eventual production (in concert with industry and the other NASA centers) of a state of the art laser light scattering instrument for use on the space station.

The MMSL has access to extensive computing facilities. Nearly all of the instrumentation in the laboratory operates under computer control and the laboratory maintains the facilities necessary to develop the operating software. There is also access available to a network of engineering/science workstations (which are mainly used for experiment modeling), the NASA Lewis mainframes and Cray X-MP supercomputer. In addition, a large number of personal computers are available throughout the Materials Division. As a result, word processing, mechanical and electronic CAD, spreadsheet, and database capabilities are easily accessible to MMSL customers.

The Laboratory also maintains small, dedicated machine and electronics shops as well as a metallography laboratory for use in the development and analysis of experiments.

The NASA Lewis Microgravity Materials Science Laboratory was designed to be a place where a researcher with an interest in microgravity materials science or an idea for potential space experiments can visit to easily and inexpensively explore these ideas at minimum financial risk. The laboratory is staffed and equipped to make such use easy and productive. Information on the laboratory is available by contacting:

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(216) 433-5013

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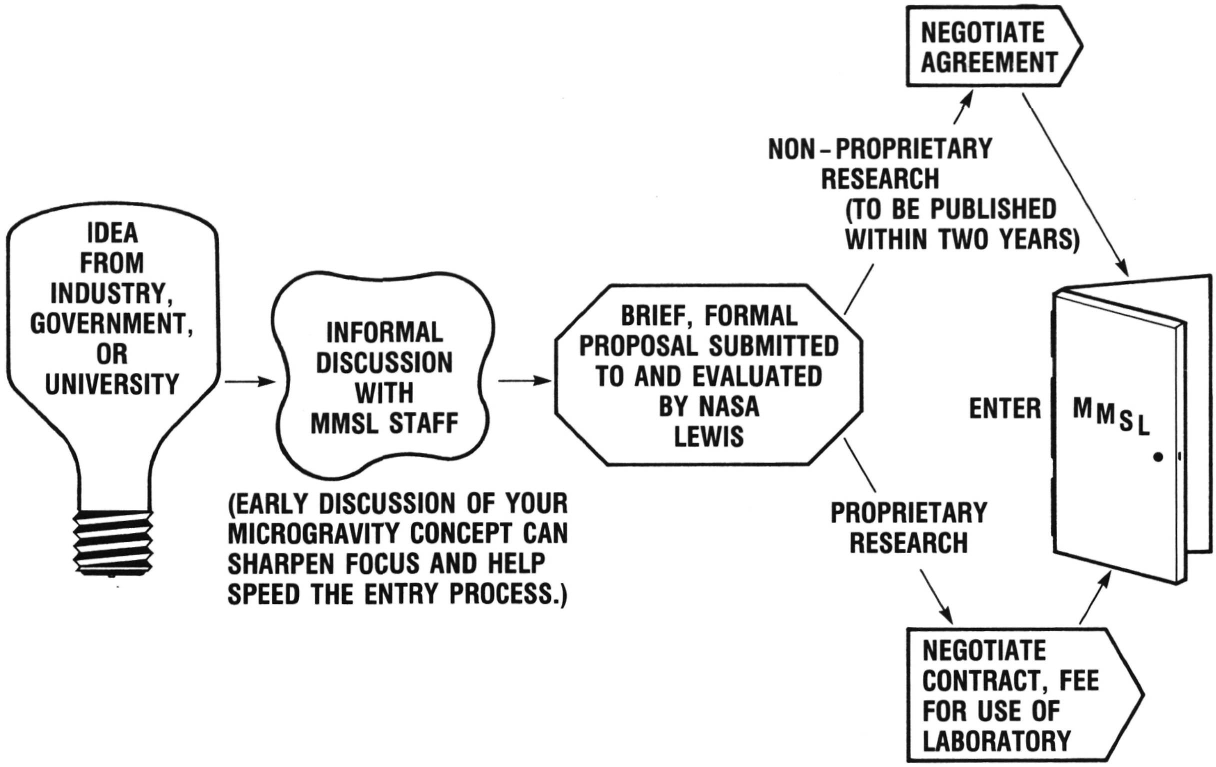

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FIGURE 1. - PROCEDURE FOR GAINING ACCESS TO THE MICROGRAVITY MATERIALS SCIENCE LABORATORY.

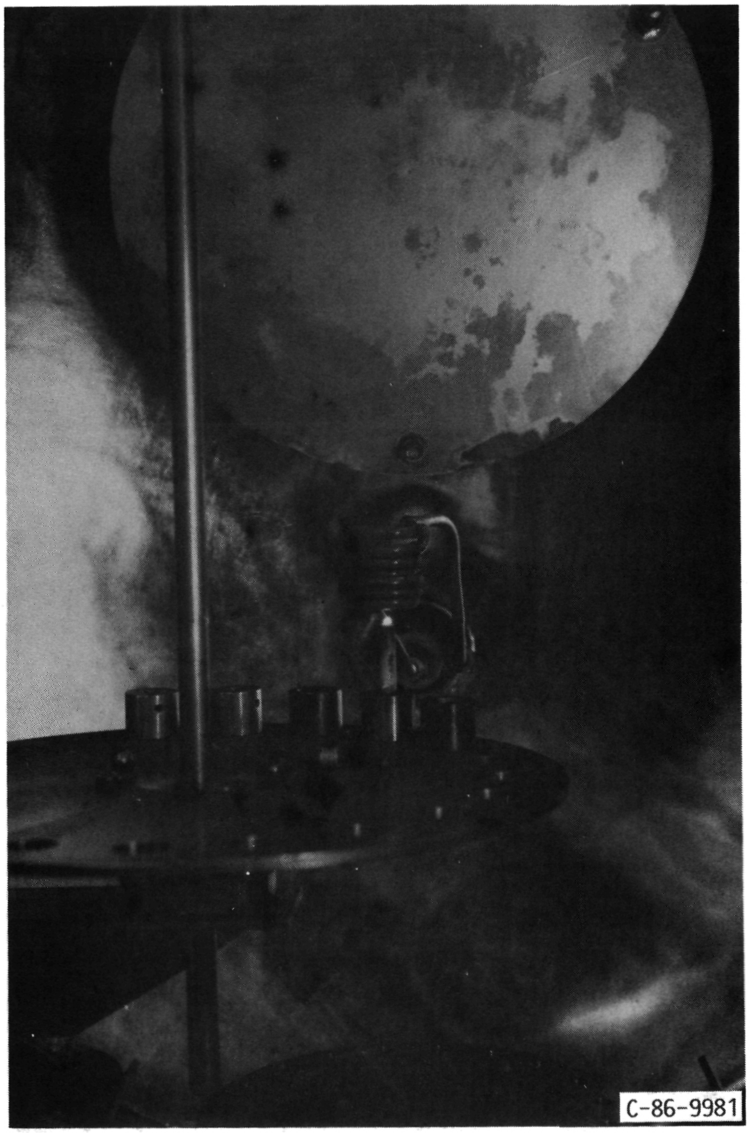

FIGURE 2. - A VIEW INSIDE THE VACUUM CHAMBER OF THE ELECTROMAGNETIC LEVITATOR SHOWING THE COIL, AND A SAMPLE ON THE SAMPLE CHANGER.

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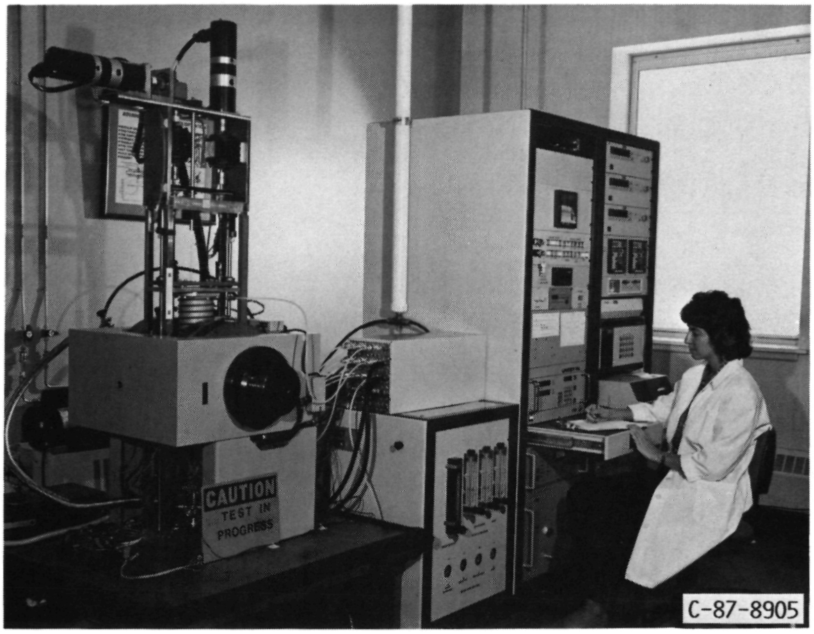

FIGURE 3. - THE MAGNETICALLY-DAMPED HIGH-TEMPERATURE DIRECTIONAL SOLIDIFICATION FURNACE. THE FURNACE ASSEMBLY AND MAGNET ARE ON THE LEFT SIDE, WITH THE CONTROL ELECTRONICS IN THE CABINETS ON THE RIGHT.

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16. Abstract

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