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COMMERCIALIZATION OF
MATERIALS PROCESSING IN SPACE

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ABSTRACT

The primary motivation of the Materials Processing in Space program is the scientific and commercial utilization of the effects of the unique environments of space on material processes. The reduction or elimination of the pervasive influences of gravity on Earth-based process mechanisms affords opportunities for understanding and improving ground-based processing or producing select materials in space which, typically, would be of low volume, high value commercial interest. Additionally, the unlimited, if not “hard” vacuum of space affords equally interesting influences on material processes. To evolve the commercialization of Materials Processing in Space, the program seeks to establish and demonstrate the scientific/technological precepts for analyzing and using the space environment and, in parallel, to establish the legal and management mechanisms to implement commercial ventures.

INTRODUCTION

The interest in the behavior of materials in low gravity grew out of a variety of disciplines. The earliest and most compelling need to understand fluid behavior in a spacecraft grew out of the propellant management program. This effort spawned a number of excellent studies of fluids dominated by surface tension and inertia in partially filled containers. Perhaps the first requirement to understand the solidification process in a low-g environment originated from the development of phase change thermal control studies. Studies on the erection of large structures in space prompted questions concerning the behavior of metals during welding and brazing processes in low gravity. It was recognized that the low-gravity environment offered unique advantages for processing metals in their molten state, and a number of manufacturing processes to be carried out in space were postulated for the production of improved or unique products.

APOLLO EXPERIMENTS

Several demonstration experiments were carried out during the Apollo flights. It was shown that in the absence of gravity, heat flow in fluids was predominantly by conduction. It was also found that the only observed flow in a simple static electrophoresis demonstration experiment resulted from electroosmosis. A low temperature casting was carried out on Apollo 14. A dispersion of sodium acetate globules ranging from microns to millimeters in diameter was obtained.

SKYLAB AND APOLLO-SOYUZ EXPERIMENTS

Skylab offered the first opportunity to carry out extensive experiments in space processing of materials. A total of 15 experiments and 9 demonstrations were conducted. The complement of experiments included crystal growth, metal composites, eutectics, welding and brazing, fluid effects, and combustion processes.

The Apollo-Soyuz Test Project (ASTP) carried 12 space processing experiments and 3 demonstrations. Several of these were similar to the Skylab experiments where verification and refinements were required. In addition, two electrophoresis experiments were attempted on the ASTP.

SPACE PROCESSING APPLICATIONS

ROCKET (SPAR) PROJECT

The SPAR Project was established to provide some continuity between the ASTP flight and the advent of Shuttle. This rocket program provides a number of short-duration (5-7 minute) flight opportunities for a number of investigators to continue their research in low-gravity phenomena and to develop concepts and techniques to be used later in Shuttle flights. To date, five SPAR rockets have flown experiments. Figure 1 depicts a typical SPAR payload.

The low-gravity environment on SPAR was found to be excellent; levels of $10^{-5}$ to $10^{-6}$ g were maintained during the coast period. However, the short-duration and harsh launch environment, including spin-up and spin-down, provide a
real challenge for experiment design and limit what can be accomplished scientifically. Despite these limitations, SPAR has been successful in maintaining a cadre of experienced groups interested in conducting materials research under low-gravity conditions. The scientific goals have been worthy, and many of the research ideas to be carried out on the Shuttle emerged from these experiments. Considerable experience has been gained in developing and testing new hardware, and an impressive inventory of off-the-shelf hardware has been built up that can also be used to conduct longer-duration experiments which will be flown on a space-available basis during Shuttle operations. Finally, and perhaps more important, considerable experience in developing low-cost hardware and experiments has been gained during this program.

SPACE SHUTTLE SPACELAB MATERIALS PROCESSING IN SPACE PLANNING

There has been considerable emphasis on investigating processes in the early suborbital and orbital experiments that could rapidly lead to the production of commercially viable products in space. While a number of interesting results were obtained, it became clear that considerably more research was required before commercial space processing could become a reality. Careful experiment design was required to take advantage of the space environment and to avoid some of the more subtle problems that are often masked by gravity-driven convection. It also became clear that much more sophistication was required in process control and diagnostics, particularly with regard to the control and measurements of thermal gradients and quenching rates required for many of the processes. Sample preparation is especially critical when it is necessary to control oxide formation or to completely homogenize a mixture. Precise positioning and rotational control that can prevent the sample from contacting the container wall without exerting disruptive accelerations or stirring within the sample are required for containerless processing. Better methods for obtaining flow and temperature fields are necessary in order to observe what is happening during a process.

Another major difficulty that became apparent in attempting to develop commercial applications for space processing from these initial experiments was the identification of potential products. A number of studies have been carried out on the economic benefits of manufacturing specific items such as silicon ribbon, improved turbine blades, and various pharmaceuticals in space. Although such studies may have had some value for creating interest, stimulating ideas, and developing concepts, they ignored certain realities, i.e., it was tacitly assumed that space processing would result in a superior product and that improvements in Earth-based technology were limited irrevocably by gravitational effects. As it turns out, many of the desired improvements in commercial products have already been achieved by alternative techniques. In other cases, new technology has supplanted the need for the product. This will always be a problem with trying to identify specific needs 10 to 20 years hence.

The present philosophy underlying the Materials Processing in Space program places the highest priority on demonstrating the advantages offered by the space environment for preparing materials and studying materials processing. Such demonstrations should stimulate researchers and commercial users to work with NASA on a cooperative basis in order to gain access to the space environment for their own purposes. Ultimately, it is expected that privately funded commercial utilization of space for materials processing will occur. It is not possible at this time to predict exactly what product will be produced or how it will be produced. This will be largely determined by the ingenuity of the people doing research on Materials Processing in Space, the imagination of the entrepreneurs, and the laws of economics. It is NASA's challenge to create the proper environment for this to occur by stimulating research on the ground to develop new ideas for flight experiments, by developing flight hardware that is responsive to experimenter needs in control and diagnostics, by providing easy access and multiple flight opportunities for qualified researchers to perform experiments, and by developing satisfactory patent protection and rights to private corporations to insure them a reasonable chance of return commensurate with their financial risk.

SHUTTLE/SPACELAB FLIGHT EXPERIMENTS

The first group of investigators to conduct materials processing experiments on a Shuttle mission has been selected. This selection was made by the Associate Administrator of the Office of Applications (now the Office of Space and Terrestrial Applications) based on recommendations from a specially appointed peer review committee and from the Applications Steering Group. The objectives and rationale for these experiments are briefly summarized in the following sections.

The experiments in the first set take advantage of the greatly reduced convective flow which provides quiescent growth or solidification conditions with precise control of temperature, growth rate, and composition. These crystal growth experiments embrace fundamental process investigations on Hg1-xCd_xTe wide bandwidth semiconductors, Pb1-xSn_xTe infrared detectors, crystal alloy semiconductors, HgI2 nuclear radiation detectors, and MnBi/Bi magnetic composites.

The next set of experiments involves glasses or glass processes. These take advantage of the containerless aspects of space processing as well as the absence of Stokes bubble rise to investigate phenomena that cannot be unambiguously studied on Earth, such as freezing (i.e., elimination of bubbles from molten glass) glass, bubble centering mechanisms for the production of highly concentric glass spheres, and
the investigation of new refractory oxide glasses.

The remaining experiments depend primarily on the absence of sedimentation to keep a material of different density in suspension during a process. These experiments include the preparation of AgCl/Al₂O₃ solid electrolytes, the investigation of immiscible alloys, and the production of uniform size latex microspheres for calibration and medical purposes.

SHUTTLE/SPACELAB FLIGHT HARDWARE

Materials Experiment Assembly (MEA) - The first article of new materials processing hardware to be flown in Shuttle is the MEA which will be delivered in mid-1980. This is a self-contained package that can accommodate any four SPAR-type experiment assemblies. It is planned to incorporate the apparatus in sealed enclosures to provide a pressurized environment because SPAR hardware was not designed for long duration in the space vacuum. Figure 2 provides a sketch of the assembly.

The configuration of the MEA is a box 169 cm x 109 cm x 106 cm. It has a mass of 800 kg and carries up to 1500 amp-hours of batteries. Experiment sequencing, control, and data acquisition is done automatically by microprocessor. Data storage is by a buffer memory which is periodically dumped into an incremental tape recorder. There are now provisions for downlinking of data.

Thermal control and experiment heat rejection are accomplished by means of a self-contained coolant loop that is connected to a radiator on top of the package.

The purpose of the MEA is to provide an easy way to integrate packages that can provide frequent flight opportunities on a space-available basis. It is planned to have at least one flight opportunity before Spacelab 3 in order to give investigators in later experiments an opportunity to perform some precursory experiments.

Later flights will be used to accommodate other investigators brought into the program. Also, some of the presently approved SPAR experiments may prove to be excellent candidates for longer duration, orbital flight test, and could be accommodated by the MEA.

Finally, it is anticipated that private institutions may wish to lease the facility from NASA to conduct experiments of a proprietary nature. The legal and financial aspects of this are being clarified.

Spacelab Apparatus - The major equipments presently under development for use on Spacelab consist of a Fluid Experiment System (FES), a Solidification Experiment System (SES), and an Acoustic Containerless Processing Module (ACPM). These facilities are designed to accommodate the experiments described in the previous section. To assure the compatibility of facilities with experiments, the chosen Principal Investigators participated in developing the specifications for the facilities and will be involved in the various design reviews.

The materials processing systems can be divided into two groups: those that are located in the pressurized Spacelab Module (Figure 3) and those that are located on the Spacelab Pallet (Figure 4). The decision on the location of a facility was largely dictated by power and heat rejection requirements. The pallet can be flown as a passenger on various satellite deployment missions. In this manner, the entire Shuttle resources are available after the satellite is deployed, and power levels of 4.5 kW can be obtained. The experiments on the pallet will be monitored and controlled remotely from the Shuttle flight deck. The experiments in the module are generally restricted to less than 1.2 kW. They have the advantage of direct hands-on interaction by the Payload Specialist.

The FES is mounted in a double rack in the module. Experiments are conducted in interchangeable cells which have parallel optically flat quartz walls. Precise thermal control of walls and interior fluid is maintained by heaters that can be programmed to give desired heating or cooling rates. Optical techniques will be used to observe fluid behavior.

Specially designed apparatus such as a low-temperature reversible gradient furnace, latex chemical reactor, and a thin flow chamber are being designed to accommodate experiments in the pressurized module.

The facilities to be located on the pallet are the ACPM and the SES. The ACPM employs acoustic positioning to control the position and rotation of a sample up to 35 mm diameter. The sample is to be heated radiantly to temperatures up to 1600°C. Provisions are desired to automatically remove and insert samples and to inject gas bubbles into a molten sample. The processes will be monitored remotely by means of a high-resolution television camera and permanently recorded by means of a movie camera.

The SES is a modular furnace facility which can accommodate up to 24 samples that are automatically loaded and unloaded by command. The furnace will accommodate sample ampoules up to 32 mm in diameter and 254 mm long. The samples can be processed isothermally, with a gradient, or directionally solidified. This is accomplished by program control and by placing the appropriate thermal interface around each sample before it is loaded into the automatic sample exchange system.

GROUND RESEARCH PROGRAM

Each of the flight experiments described previously represents a major commitment on the part of the Principal Investigator and NASA to an extensive ground-based re-
search program. The objectives of the programs are to de-
velop the experiment protocol, prepare the samples, test the
apparatus, and develop the analysis procedures; but, in addi-
tion, the Principal Investigator is expected to explore the
best possible techniques that can be employed on the ground
to accomplish the experiment objective. For example, in
most of the Skylab and ASTP experiments, the flight samples
were compared to samples processed under identical condi-
tions on the ground to elucidate the effect of gravity. While
this is an excellent control and should certainly be done, it
by no means represents the best that can be done on the
ground, because the process used was not generally optimiz-
ed for a one-gravity environment. For example, crystal
growth experiments done in space should also be compared
to results that can be obtained by using the best techniques
for stabilizing against convection; e.g., stabilizing geometries,
magnetic fields, etc. Periodic reviews by experts in the
field are being conducted to provide constructive criticism of
the experiment and to suggest possible improvements. A final
science review will be held before the experiment is com-
mitted to flight to determine the adequacy of preparation.

In addition to developing good research to be carried out in
space, it is also recognized that it is essential to develop new
techniques for accommodating the experiments. Included is
developing and adapting state-of-the-art technology to
specific problems in the Materials Processing in Space pro-
gram, such as: high-temperature heat pipe furnaces with
precise thermal control; new measurement techniques such
as localized fringe holography, laser doppler velocimetry,
and high-resolution thermal imaging systems; improved
techniques for heating and quenching samples; new contain-
erless position control techniques, etc.

COMMERCIALIZATION

The ultimate goal of the Materials Processing in Space pro-
gram is to develop a viable commercial interest in using
space to: (1) perform research to improve industrial tech-
nology or to develop new products, (2) to prepare research
quantities of material to serve as paradigms with which to
compare current Earth-based technologies, (3) to manu-
facture limited quantities of a unique product to test market
potential or to fulfill a limited but compelling need, and (4)
to produce materials in space of sufficient quantity and value
to stand on their own economically.

It is recognized that it will be necessary for NASA to go
more than halfway toward demonstrating to potential
industrial users that they can learn more about their process
by conducting experiments in space as well as do things in
space that they cannot do on Earth. This can best be accom-
mplished by working closely with industries to the point of
understanding their problems sufficiently to identify areas
in which space processing can best be utilized. It is probably
not realistic to expect major commitments from industry
alone until we have completed a sequence of spaceflight
opportunities and have been given a chance to demonstrate

the potential that space offers. Also, better ways must be
found to select experiments for flight, protect the propri-
etary rights of the customer, reduce the lead time, and lower
the costs of conducting experiments in order to attract the
private industrialist.

An important first step will be the establishment of joint
endeavors with industrial users to assist them in exploring
areas where Materials Processing in Space can be utilized
to meet their own needs. In general, these joint endeavors are
envisioned to be "constructive partnerships" between NASA
and industrial firms wherein the parties are seen as equals
who have enough common objectives to make the endeavor
worthwhile for both. Also, arrangements are being worked
out to lease NASA facilities and for cooperative development
facilities. Increasing commitment on the part of the user will
be required as the project matures.

A special NASA team has been created to work exclusively
with commercial interests. This team forms a bridge between
NASA and the commercial world, serving as a source of in-
formation and assistance for the user as well as a focal point
for commercial views and a channel by which these views
can be articulated to NASA. This team is also working to
obtain clarification of patent protection rights, proprietary
rights, liabilities, leasing policy, and pricing. It is through this
effort that NASA believes it can provide a simpler interface
to the outside world, develop a better understanding of the
incentives needed to elicit private initiatives, and stimulate
the inventive genius and entrepreneurial spirit in this country
to fully utilize the benefits to be derived from the Materials
Processing in Space program.

Predicated upon the current understanding of industrial
technical interests and requirements for Materials Processing
in Space, definition studies are being pursued on advanced
materials processing carriers to accommodate mission dur-
ation, utilities, and sample requirements. One such capabil-
ity can be achieved with the Materials Experimentation
Carrier (MEC) which is an extension of the MEA concept
attached to the 25kW Power Module in the free flying mode.
Figure 5 depicts the MEC with four commercial processing
units. Figure 6 depicts the planned evolution of Materials
Processing in Space from a NASA sponsored technology
characterization to industry sponsored research and commer-
cial application.
SPAR PAYLOAD III

GENERAL PURPOSE ROCKET FURNACE GAS MODULE

OGIVE RECOVERY SYSTEM ASSEMBLY

TEMPERATURE CONTROL UNIT FOR 74-18 (MSFC)

SUPPORT MODULE

APPARATUS FOR EXPS. 74-45 (ROCKWELL) & 74-53 (MIT)

APPARATUS FOR EXP. 74-36 (GRUMMAN)

ELECTROMAGNETIC LEVITATION FURNACE FOR EXP. 74-48 (G.E.)

MEASUREMENT MODULE

NOSE CONE LENGTH 51.8"
SCIENCE P/L 114.625
SUB-TOTAL (SCI P/L + NOSE CONE) 166.425"

MSFC-77-PA 4000-476E

Figure 1.
MSFC
MATERIALS EXPERIMENTS
ASSEMBLY (MEA)

THERMAL RADIATOR

109CM

169CM

EXPERIMENT APPARATUS

DATA MANAGEMENT SYSTEM

BATTERY

Figure 2.
MATERIALS PROCESSING IN SPACE
LONG RANGE PLAN


APOLLO SKYLAB APOLLO-SOYUZ
PRECURSORY EXPERIMENTS

25 KW POWER MODULE

MATERIALS RESEARCH & TECHNOLOGY

TRANSITIONING THE TECHNOLOGY OF MATERIALS PROCESSING IN SPACE TO THE PRIVATE SECTOR

MATERIALS PROCESSING APPLICATIONS

NASA SPONSORED RESEARCH

NASA/INDUSTRY PROCESS DEMONSTRATIONS

COMMERCIAL UTILIZATION

Figure 6.