Chapter 8

MATERIALS PROCESSING IN SPACE

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Chapter 8
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INTRODUCTION

The primary motivation for pursuing materials science and engineering in space is to use this low-gravity environment for scientific and commercial applications.[1] Removing the effects of gravity offers a new dimension in controlling process variables such as convection, composition, and fluid flow. This may create opportunities for understanding and improving ground-based production methods and, where economical, manufacturing select materials in space.

NASA research on materials processing in space (MPS) research started in the late 1960s with relatively simple demonstration experiments in solidification, fluid dynamics, and electrophoresis conducted during the Apollo missions. Further MPS experiments were carried out during the three Skylab missions and during the Apollo-Soyuz Test Project (ASTP). During the hiatus of manned space flight, between Apollo and the Shuttle, NASA continued its MPS research by using the SPAR (Space Processing Applications Rocket) sounding rocket program, drop tubes and towers, and research aircraft flying parabolic trajectories. The majority of future MPS research will be conducted on the Shuttle, free-flying platforms, and eventually on a space station.

Neither the scientific nor the commercial value of materials research in microgravity is fully understood. **Although there may be near-term commercial MPS applications (e.g., certain pharmaceutical products), the true value of the microgravity sciences will not be known until years of basic research and significant improvements in space-based hardware have been accomplished.** The National Aeronautics and Space Administration's (NASA) MPS program, operating with a modest annual budget ($27 million in 1985), has identified several scientifically interesting phenomena with potential commercial value. To date, this program has met with limited success both in attracting private sector participants and in identifying commercially valuable products and services. Nonetheless, there is a strong belief in both the scientific and industrial communities that MPS research will eventually lead to dramatic breakthroughs in terrestrial and space-based products and processes. To assist this process, NASA established an Office of Commercial Programs in September 1984 to provide a focus for NASA research with potential application and to expand U.S. private sector investment in technologies with commercial potential.

MPS research and hardware development are being pursued with interest in Europe and Japan. In Europe, West Germany has long maintained the most vigorous national MPS program; the European Space Agency (ESA) has recently begun to conduct a wide range of MPS activities. European enthusiasm for MPS research stems from ESA'S commitment to the development of Spacelab and, as in the United States, from a belief that basic MPS research may eventually lead to important scientific and economic rewards. As a result of ESA Spacelab and other MPS activities, it is likely that Europe will become an important source of published information on the behavior of materials in microgravity. **The Europeans have positioned themselves well to exploit future MPS products and services if they prove commercially valuable.**[2]

MPS is not yet an area of international commercial competition: there are no MPS products and the demand for equipment and services is generated primarily by the various government space agencies. **The most important international issue in MPS is how to make the most effective use of cooperation to share the costs of research and to realize the benefits of this new technology more quickly.**

[1] The gravitational attraction of Earth on a spacecraft in a 400-km orbit is only about 12 percent less than it would be if it were on the Earth's surface. However, the phenomena of weightlessness occur because the spacecraft and its contents are in a state of free fall. A spacecraft which has achieved orbital velocity has a gravity environment of about 10-7 g (1 ten-millionth of Earth's gravity).

[2] Foreign ability to compete in space manufacturing will depend strongly on availability of the Shuttle to foreign users or on the development of suitable foreign launch vehicles and carriers.

Some of the MPS potential applications for the microgravity environment are:[3]

- **Processing of biological materials:** Such diverse tasks as the isolation of beta pancreatic cells to determine how the production of insulin is regulated, the isolation of cells from organs that produce various hormones and enzymes such as urokinase and erythropoietin, and the purification of proteins for research and as pharmaceutical products may be accomplished in microgravity. On Earth, convection, sedimentation, and buoyancy inhibit the separation of certain lighter-density materials. In microgravity, separation techniques such as electrophoresis, isoelectric focusing, and suspension cell culturing may be accomplished with greater efficiency and higher purity.
- Production **of large perfect crystals:** It may be possible to produce certain types of crystals in space for use in semiconductors, solar ceils, infrared detectors, and other electronic devices. On Earth, the chemical homogeneity and size of crystals are limited by convection- and gravity-induced growth defects. It may be possible to control these parameters and minimize defects in the microgravity environment of space.
- **Production of glass and ceramics:** The microgravity environment may allow the production of special glasses that are useful in optical fibers, high-energy laser applications, and fusion research. Use of containerless processing could eliminate the problems caused by nucleation and reduce trace impurities that limit the applications of high-purity glasses. Such space-based techniques could extend the glass-forming range of many materials and result in new and unique glasses with exotic properties. MPS research may also help to improve glass processing on Earth by providing information on how to eliminate gases in glass, and improving homogeneity through chemical interaction. Ceramics must be prepared by sintering at such high temperatures that they are almost invariably contaminated by the container in which they are made. Containerless processing may offer valuable research opportunities for the preparation of high-purity ceramics.
- **Studies of fluid and chemical processes:** Such studies would be designed to understand the effects of convection. This research would be applicable to the study of continuous-flow electrophoresis; dendritic growth processes; the growth of very delicate organic crystals; and the nucleation, growth, and coalescence of bubbles, flocculants, colloids and hydroSOIS. Apart from the basic scientific interests, such studies have important applications in many industrial processes.
- **Investigation of metals, alloys, and composite materials:** Microgravity allows research into the basic properties of pure metals, macrosegregation and microsegregation during solidification of alloys, the role of gravity-driven convection in the microstructure of castings, and the preparation of alloys or composites having components with large density differences. Space-based metallurgical research may result in the development of terrestrially useful products such as high-temperature turbine blades and new battery technologies.

[3] See: *Materials Processing in Space,* **Committee on Scientific and Technological Aspects of Materials Processing in Space, National Research Council, 1978;** *Materials Processing in Space: Ear/y Experiments* **(Washington, DC: NASA SP-443, 1980);** *Materials Processing in the Reduced Gravity Environment of Space,* G. E. Rindone (cd.), **Proceedings of the Materials Research Society, vol. 9, 1982.**

MPS ACTIVITIES IN THE UNITED STATES

NASA Research

The NASA MPS program (recently renamed the Microgravity Science and Applications [MSA] Division) is a responsibility of the Associate Administrator for the Office of Space Science and Applications (OSSA) and is directed and administered by the Director, MSA Division, at NASA Headquarters. The Director, assisted by a Scientific Advisory Committee, determines policy, objectives, and priorities, and allocates program resources. NASA materials processing research is being conducted at Marshall Space Flight Center, Jet Propulsion Laboratory, Johnson Space Center, Lewis Research Center, and Langley Research Center. There are also approximately 100 university and industrial investigators currently working with NASA on MPS-related projects.[4] NASA solicits proposals for research tasks from the scientific community and funds them on the basis of merit (established by a peer review process) and relevance to current NASA programs.

NASA's research activities in MPS have focused on the role played by gravity in materials processes and the development of better control of the composition, structure, and morphology of materials processed in space. The MPS program currently supports research in metals and alloys, electronic materials, biotechnology, glasses and ceramics, combustion, and fluid dynamics and transport phenomena.[5]

NASA still uses sounding rockets, drop-tubes and towers, and research aircraft in its MPS work; however, the Shuttle is, at present, the only means by which to conduct long-duration microgravity research. In order to facilitate Government and private research on the Shuttle, NASA has developed or encouraged the development of a range of Shuttle-related, reusable MPS hardware. Although this equipment is described in greater detail later in this chapter, it is useful for the purposes of this discussion to list the means by which MPS research is or will be carried out (table 8-1).

[4]Hearings on Materials Processing in Space, Before the Subcommittee on Space Science and Applications of the House Committee on Science and Technology, 98th Cong., 1st sess., Statement of Richard Halpern, Director, NASA, Microgravity Science and Applications Division, Sept. 14, 1983.

[5]Ibid.

Table 8.1 .—Characteristics of Shuttie Payload Carriers

	GAS	HITCHHIKER-G	SPARTAN
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Polntlng	None llmlng of payload opemt!o. s can M cmdlnated wllh m+r payload po, ntlng raqulremems Ttu more s xlflc re@fefnents **the nwe YOU MM your oppormnkm**	Shuttle bny pointing possible	z 3 arc-mln stellar : 1020 .3 K.sec S,I.,
Payload Size	1975 Inches radius 2825 !nches or 14 13 inches hqh	Dependtn! on CG	Sue of SPARTAN carrmt IS m,ss,cm ~Pn~nt Dhnensions of SPARTAN 1 are 31 89 I 31 89 , 2205 I,,, For SPARTANS 2 and 3 slMlc ● nvelop r.dial llmlt, ~, 8563 ● cross the bay ● nd S1 18 ● lcmg the ba,
Psyload Wmght	200 lbs IDO lbs Or 60 lbs	Currently the 141tchh#ker.G Is restrkled to payloads wetghlng 10ss lhsn 750 pounds twth ● chotce o? several modes of ● ccommodations depending on sam●nd Weight	500 lbs (for experlmenl)
Last Acc8,8 Befo,e Launch	2-3 months	2 months	1 month
F1r8t Access After Lmdkng	2 Weeks	2-3 **weekc**	**1** week
Mlaskm Spulallct Pa ftlclpatlon	Dpemte two toggle swltchas snd power on+ff switch	L)mnti	Pre-relmti checkout, gwno go ● la!", ch~k pce.rekease of bltef ● nd payload Cwbeniatlo" release recapture
Fmquoncy of Launch OppO@.nlty	Approximately SO per yew, 29 have flown ● s of Octobol 1s64	Currently ooe evefy SIX months	2 year bulldlng to 11 by 1990
Testing fioqulmrnents	591*	Sdrty	**way**
Led T!me	11.13 month- Lmfore launch	Six mooths from Initiation to Night	In.wwnw-d dependent with ● m~nlmum 0! nine rnomh.
OOcuwmnt*tlOn	Dfswlngs, Dk.cwkcsl snd m.chankd schemal~cs chamkal ● nd bkoqcal balance equmtlona. heat flow dbgrams, smembly ● nd handllng procedures sdety hazard repwls	OOcuwmnlstJOn rqukements currently under development	Intertace ~fmllmn ● nd safety pack~.
M18alon D"ratlon	Shuttle ftight duration or llmlted by battery supply	Shunk@ IUghl dur.tloo	40 hours
Power	Batlwy supply (Customer SUpphd)	Available through fhe Shuttle A $lngle payload has ● maximum S00 w ● vailable the total p8yloads have 14&3 w ● vadable	Battery Supply (GSFC SuPplled)
Upllnk or Oownllnk	None	An ● synchronous **dowdllnk** chwmel ● 1200 bsud An ● synchronous up41nk ● t 121Xl baud Medium rate downllnk channd 01 16 Kbp9 1014 Mbps	None
R.mota Cc."t,ol Pmslbklnloa	Nom	**A** HtichhUmr.G c"slorne, may bend ● llmllod number of bllevel ● nd serld commands 10 the payload	Prgprcqrammed (mlcrocomD"tor)

SOURCE: "Attached Shuttle Payload Carriers, Versatile and Affordable Access to Space," NASA, Goddard Space Flight Center, 1984,

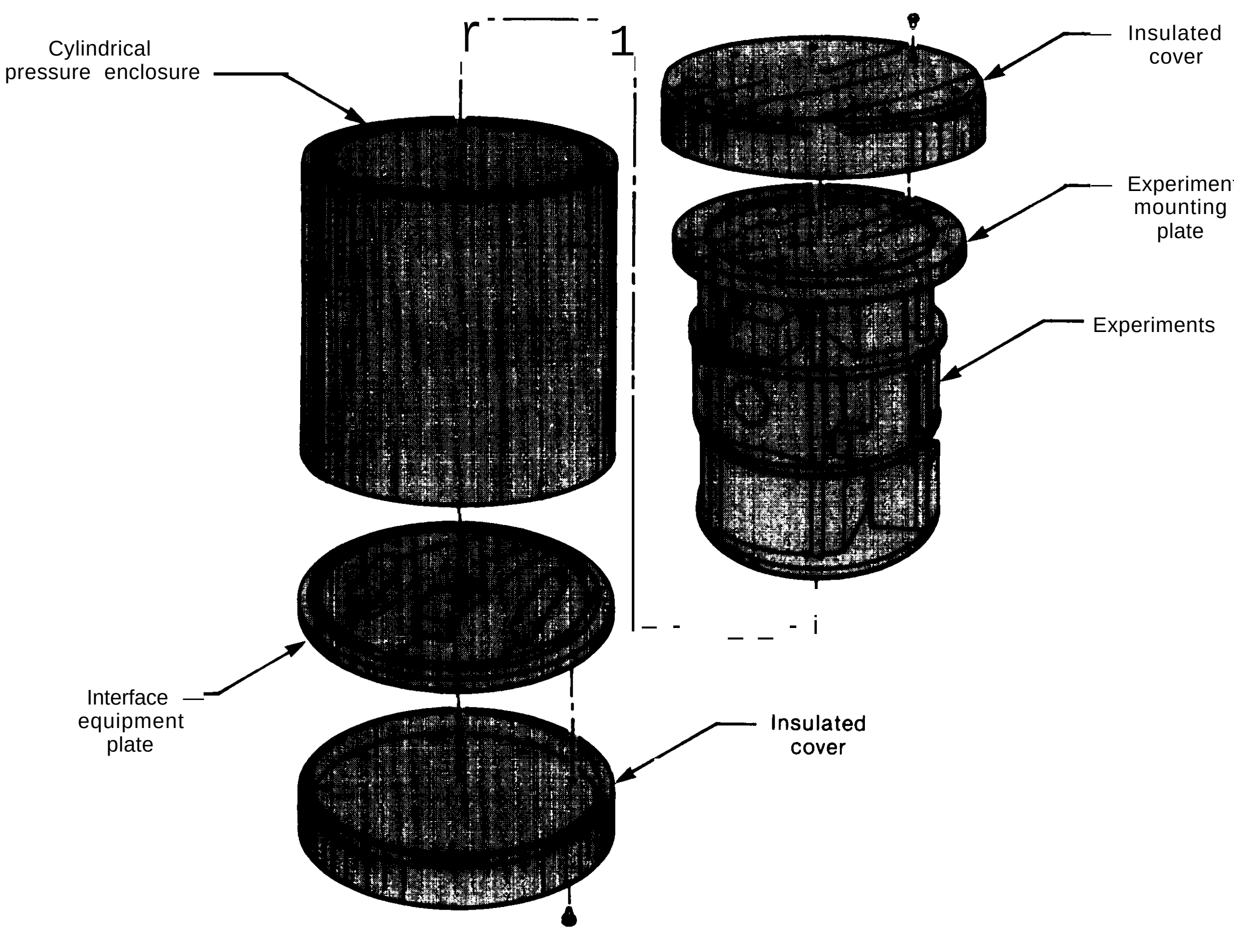
Get-Away Special (GAS) Canisters

The GAS program was developed by NASA to encourage researchers to take advantage of the unused capacity which exists on most Shuttle flights. GAS canisters, which are little more than hollow cans mounted in some manner on the Shuttle (fig. 8-l), come in two sizes: 5 cubic feet for payloads weighing up to 200 pounds and 2.5 cubic feet for payloads weighing up to 100 pounds. The experimental equipment flown in the canisters is developed by the user subject to NASA safety regulations. Prices charged for flying the GAS canisters are less than full Shuttle prices and range between $3,000 and $10,000.

Carriers

Carriers serve a similar goal to that of the GAS program–namely, to maximize the use of the Shuttle bay and reduce the cost of flying small payloads into space. NASA's current carrier program, Hitchhiker, is based on the mission-peculiar support structure (MPESS) developed by Teledyne Brown Engineering for Marshall Space Flight Center (fig. 8-2). Although Hitchhiker is still in the development stage, the MPESS—basically a truss bridge on which GAS canisters or other larger experiments are mounted–was used on Shuttle mission 7. Unlike the GAS canisters or MPESS, Hitchhiker will provide limited power and command and control functions.

Figure 8-1.—Shuttle Get-Away Special Canister



SOURCE: National Aeronautics and Space Administration.

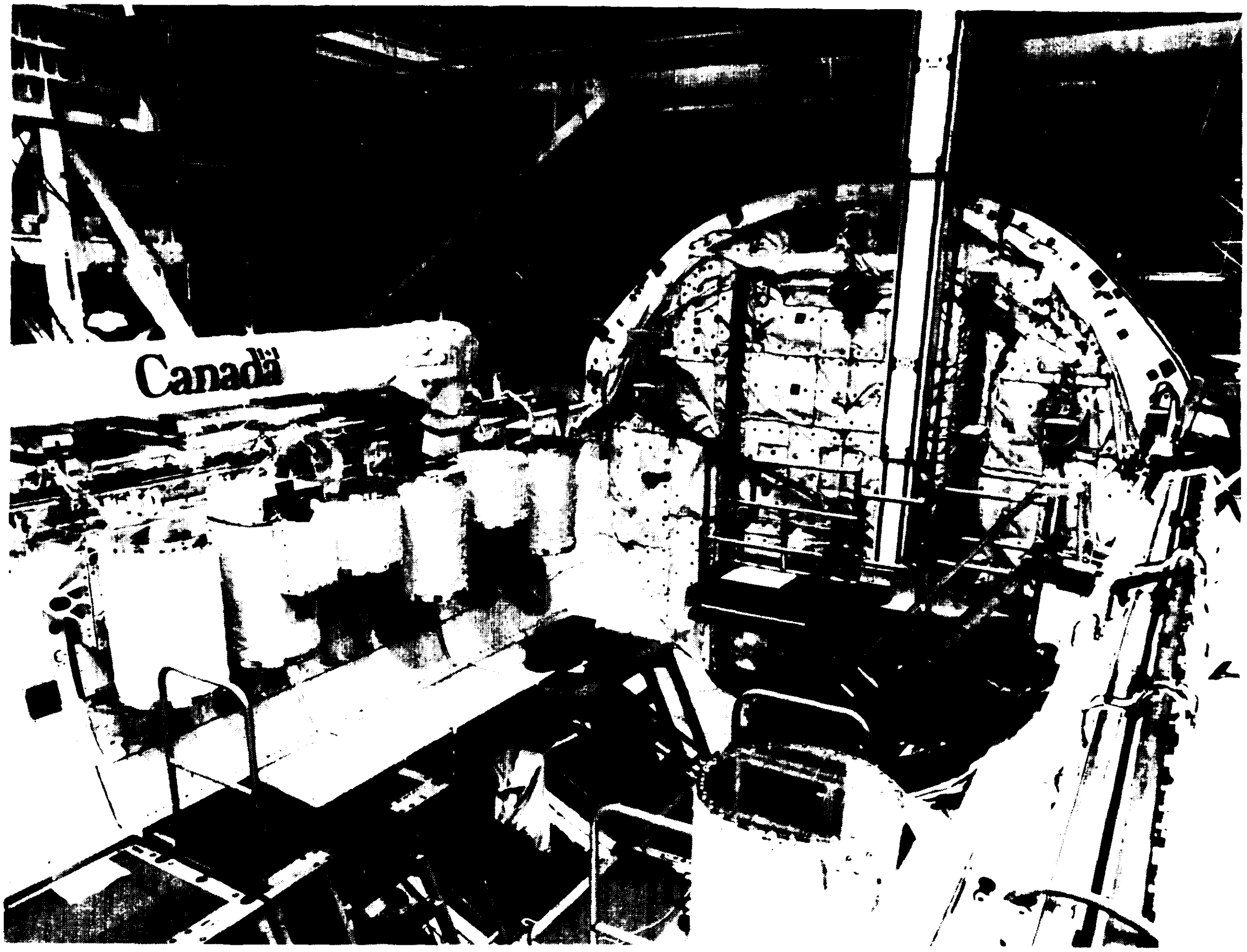


Photo credit: National Aeronautics and Space Administration

This view shows the open cargo bay of the orbiter Challenger in the Orbiter Processing Facility. On the left, the Canadian-built Remote Manipulating System can be seen and six of the seven Get-Away Special Canisters are just below it. The other Get-Away Special Canister is in the front right side of the cargo bay.

Spacelab

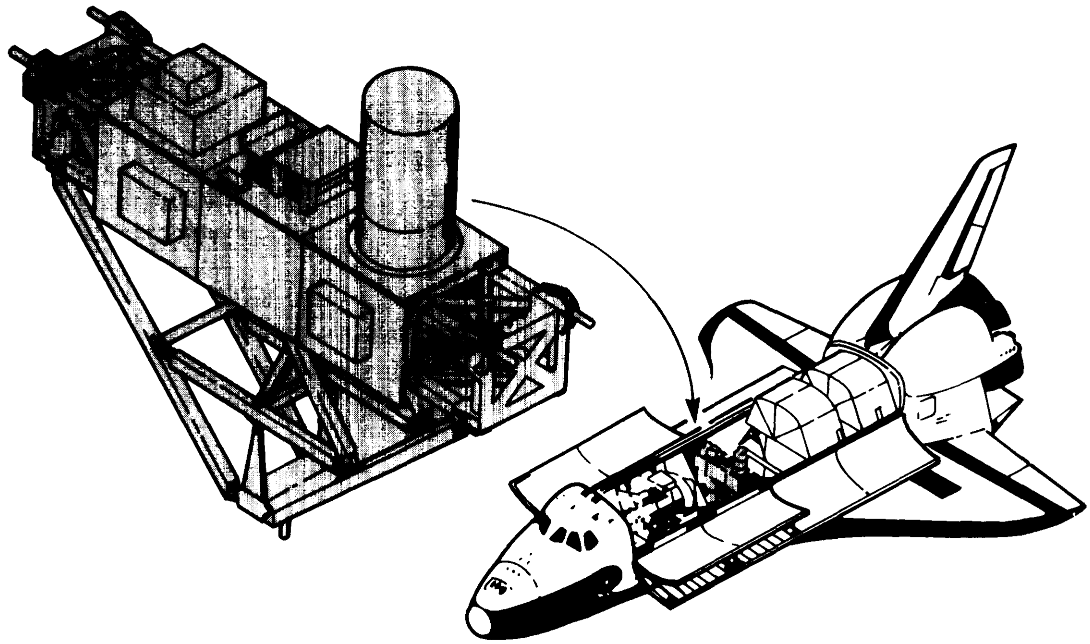
The Spacelab is a pressurized module designed to be carried in the Shuttle payload bay. It is a laboratory that allows MPS and other types of research to be done in a "shirtsleeve" environment (fig 8-3). Spacelab was developed by ESA, but pursuant to prior agreements, was transferred to NASA upon completion.

Free-Flyers

Free-flyers are unmanned carriers designed to be deployed and retrieved by the Shuttle. Such free-flying carriers will allow experimentation independent from Shuttle environmental or time constraints. Relying on technologies originally developed for sounding rockets, NASA has produced a free-flyer called the Spartan. This free-flyer will be used for astronomical and astrophysical payloads which require precise celestial pointing. Spartan will be able to operate independently from the Shuttle for up to 40 hours.

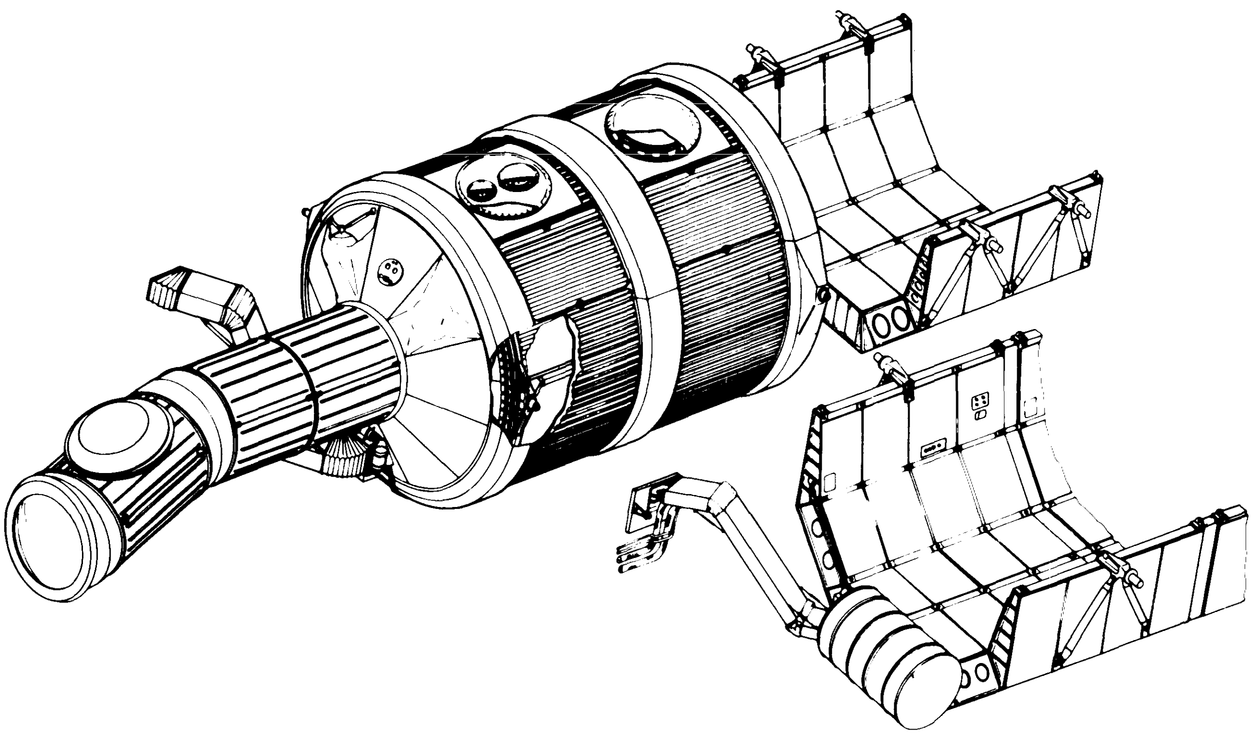
NASA is also working with Fairchild industries to develop a free-flyer called "Leasecraft." The West German Government and the West German firm MB B/ERNO developed the Shuttle Pallet Satellite (SPAS) as the first free-flyer.

Figure 8-2.—NASA-Goddard Space Flight Center Hitchhiker Payload Mounted on the Mission-Peculiar Support Structure (MPESS)



SOURCE: National Aeronautics and Space Administration.

Figure 8-3.–Spacelab Drawing of the Overall Conception of VFW-Fokker/ERNO Spacelab



SOURCE: National Aeronautics and Space Administration.

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Space Station

Although it is presently in the design stage, it can be reasonably assumed that some portion of the proposed U.S. space station will be dedicated to MPS research.

In addition to its scientific research, NASA has also tried to encourage early U.S. private sector commercial investment in MPS. NASA wanted the private sector to participate in NASA programs in a more creative manner than was possible under normal procurement contracts. To accomplish this goal, NASA established the Joint Endeavor Agreement (JEA) and the Technical Exchange Agreement (TEA). These are contractual agreements between NASA and industrial partners to cooperate on the definition, development and, in some circumstances, flight-testing of MPS experiments and hardware. Under these arrangements, no funds are transferred between NASA and the private sector participants. The type of relationship chosen by the private sector participants marks the degree of the signatories' commitment:[6]

- **Technical Exchange Agreement (TEA):** The TEA is for companies that are interested in the application of microgravity technology, but are not ready to commit to a specific space flight experiment. Under such an agreement, a company may conduct experiments in NASA grou rid-based faci lities including drop tubes, drop towers, and aircraft in order to determine whether a more elaborate space experiment is justified. Using the TEA, John Deere and Dupont have processed samples in the Marshall Space Flight Center drop tube and KC-1 35 aircraft. Joint studies of convection in electrodeposition have been carried out by INCO, and studies of the growth and purification of mercury cadmium telluride are in progress with Honeywell's Electro-optical Division. In addition, there are some 20 new research activities that are the functional equivalent of formal TEA-sanctioned projects. Research topics range from pharmaceuticals, to optical fibers, to exotic chemistry.
- **Joint Endeavor Agreement (JEA):** The JEA is an arrangement whereby NASA and a pri-

[6] Ibid.

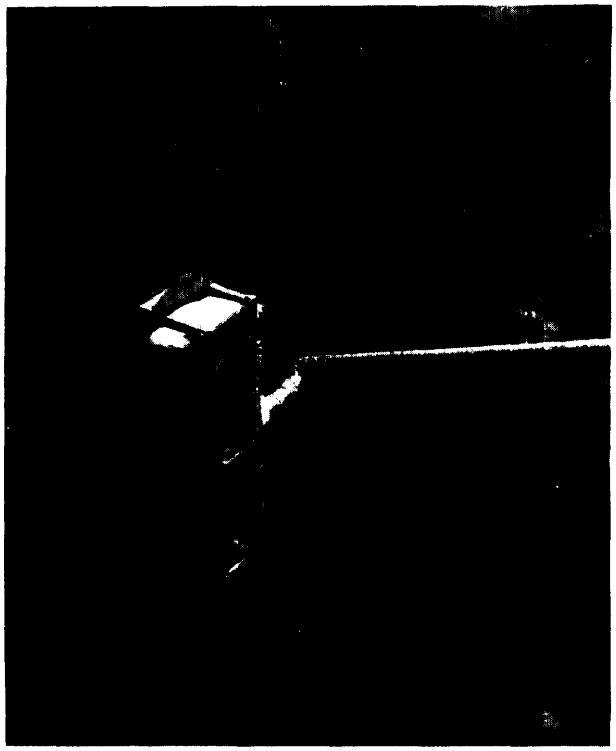

Photo credit: National Aeronautics and Space Administration

The Space Shuttle Challenger's Canadian-built remote manipulator arms grasps the Shuttle pallet satellite (SPAS-01), during proximity operations on June 22. The scene has within it a few reflections on the window through which it was photographed. SPAS-01 was developed by the West German firm Messerschmitt-Boelkow-Blohm GmbH (MBB).

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vate sector partner share the costs and risks of developing commercial space ventures. The JEA generally requires a larger financial commitment on the part of the industrial participant than does the TEA. Under a JEA, NASA's partner is expected to develop the experimental apparatus and to provide NASA with limited access to such equipment; NASA, in turn, agrees to provide access to terrestrial facilities and a specified number of space flights. In some cases, data from JEA experiments may be held as proprietary information by the firm. At the end of the JEA, should the venture become commercially viable, the company would have to pay the normal Shuttle price for all future flights. JEAs are now in effect with McDonnell Douglas, Microgravity Research Associates, Fairchild industries, Spaceco, Ltd., 3M Corp., and Martin Marietta.[7] NASA is currently giving serious consideration to a number of other JEA proposals.

Although only a small portion of NASA's annual MPS budget has been devoted to commercial activities, these activities have been widely publicized by NASA and the popular press.[8] This publicity has led to disagreements within NASA and the scientific community about the wisdom of emphasizing the yet-unproved commercial value of MPS technology. The potential for development of highly profitable space industries lends support to NASA's desires for stable or increasing science budgets and a space station. On the other hand, NASA recognized that a premature emphasis on yet-unproven technology could damage its reputation in the scientific and manufacturing community and jeopardize future funding for science projects.

[7]The Fairchild Industries JEA involves the building and flight-testing of a free-flying platform called "Leasecraft." Although Leasecraft could be used for MPS research or production, it is not limited to this application and may be used as a "common bus" for other payloads.

[8]Until recently, only about 3 percent of the NASA MPS budget was devoted to purely commercial activities. This figure is likely to increase substantially as the Office of Commercial Programs increases its scope of operations.

The Private Sector

Although there have been some recent indications of increased interest, the initial private sector response to NASA's commercial MPS program was quite reserved. There are several reasons for its reservations:[9]

Absence of Proven Products or Processes

The commercial value of low-gravity manufacturing remains largely an interesting conjecture; in the absence of conclusive experimental results or existing products, the risks involved are simply too high for most private firms. At least for the near future, the responsibility for proving the technical and economic feasibility of new space technologies will rest on the Government, acting alone or in joint ventures with the private sector.

Few Attractive Investments

Although a number of MPS products, processes, and services are currently being discussed, few of these are attractive investments. Generally, investments in MPS research involve high costs, considerable risks and long or uncertain lead times before a return on the investment could be realized.

NASA had hoped that the JEA and TEA programs would encourage a wide range of commercial space activities, but only six JEAs have been signed since the programs began in 1980. The first of these was signed in January 1980 with McDonnell Douglas Astronautics Co. (MDAC). Its purpose was to investigate the commercial viability of conducting electrophoretic separations in space; MDAC hoped that new and valuable pharmaceuticals might be developed.

The next JEA, signed in January 1982 with GTI, a California-based electronics firm, was directed towards development of a multiuse metallurgical furnace. This JEA was discontinued in January 1983 because of GTI's inability to market their

[9]U.S. Congress, Office of Technology Assessment, *Civilian Space Policy and Applications*, OTA-STI-177 (Washington, DC: U.S. Government Printing Office, June 1982), pp. 219-220, 224-229.

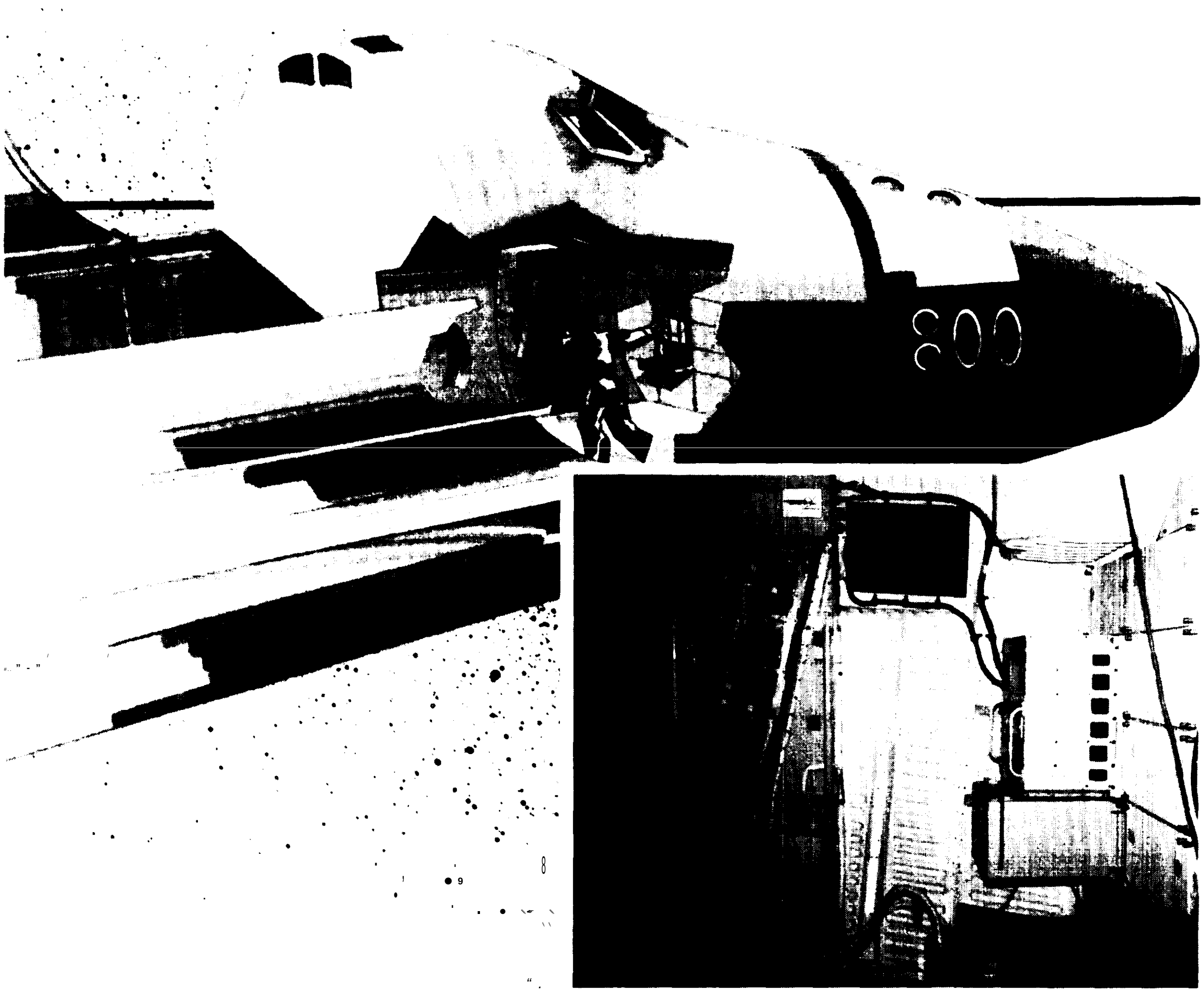

Photo credit: McDonnell Douglas

McDonnell Douglas-Ortho continuous electrophoresis device.

concept successful ly.[10] The third JEA, signed in April 1983 with Microgravity Research Associates (MRA), is directed to the study of gallium arsenide crystal growth. The fourth JEA, with Fairchild industries, has as its subject the design and flight-iest of the free-flying Leasecraft, The fifth JEA, with Spaceco, Ltd., is for the development of a Shuttle payload bay environmental monitoring instrument. The next JEA, with the 3M Corp., is for the investigation of organic polymers, crystal growth, and thin film. The most recent JEA, with Martin Marietta, is directed toward research on fluid dynamics associated in capillary propellant tanks in low gravity.

The JEA program offers many attractive benefits to its participants, such as access to NASA facilities and personnel and free flights on the Shuttle. Still, the limited private sector interest in this program is a clear indication of industry's assessment of the risk involved in pursuing MPS activities.

Entry Costs Are Extremely High

Access to orbit is very expensive and will continue to be expensive even in the Shuttle era, particularly if compared with the costs of demonstrat-

[10]Letter from James La Fluer, President, GTI, to James M. Beggs, NASA Administrator, Dec. 23, 1982.

ing the commercial viability of most Earth-based innovations. A Delta-class MPS payload including integration expenses may involve flight costs in excess of $15 million. This additional expenditure, incurred well before commercial feasibility has been established, is a departure from normal product development on Earth. The recurring costs associated with payload integration and space flight, added to the costs of starting materials, flight hardware (potentially tens of millions of dollars) and personnel, suggests that a commercial space venture would have to be assured of very high revenues before it became an attractive investment.

Although the JEA reduces startup costs by offering a limited number of free space flights (MDAC is promised 8, MRA is promised 7) a commercial venture must be able to pay its own costs after the JEA is terminated. Therefore, the cost of gaining access to the Shuttle or a space station will have a significant impact on the level of private industrial participation in MPS activities.

Fear of Terrestrial Competition

Some potential investors believe that whatever can be done in space will eventually be achievable more cheaply on Earth. Though the microgravity environment of space cannot be duplicated, new technologies have been developed which do minimize the effects of gravity on Earth. In 1980, a U.S. firm, working with NASA, developed a container-less processing system for making special glass products.[11] In this system, glass is suspended within a chamber by sound beams in a process called acoustic levitation. Similarly, new gel electrophoresis and recombinant DNA techniques may one day be able to accomplish more cheaply on Earth what McDonnell Douglas is trying to accomplish with continuous-flow electrophoresis in space.

Private Sector Does Not Control Means of Access to Space

Access to launches, launch assurances, availability of support facilities, and the cost of space transportation may all be influenced by nonbusiness considerations such as changes in an administration's space policy, national security constraints, or fluctuations in congressional and public support. If necessary space facilities are not available when needed, the resulting costly delays could be fatal to a new commercial program.

Markets for Some Space Products Are Underdeveloped

Unlike innovations that emerge in response to existing or clearly possible market opportunities, some space-based products or processes may have to create new markets. The absence of a well-defined market makes it difficult to project potential sales or return on investment; this makes it difficult to attract the financial backing necessary for such endeavors.

The difficulties encountered by GTI in its attempts to market a metallurgical furnace for research purposes make this problem especially clear. At the conclusion of a 9-month marketing effort GTI had no firm offer to fly a metallurgical sample in its furnace. Some observers have remarked that GTI erred in making a commitment to a furnace that was not versatile enough to capture the entire market in experimental solidification. Others have suggested that 9 months was too short a time in which to expect to build a market, that their price was too high ($1 5,000 to $20,000 per sample) and that their expectation of a 3-year return on investment was unrealistic. All of these criticisms reflect the difficulty of a firm's trying to define a market while already involved in the complex tasks of technology development and the management of a space-based business venture.

It would appear that the strength of the MDAC and MRA Joint Endeavor Agreements stem at least partially from the fact that the products being developed—new drugs and semiconductor materials—are intended for the large, well-defined, and dynamic pharmaceuticals and electronics markets.

Lack of Understanding of the Space Environment

Many industries that may eventually benefit from future space research are simply unaware of what microgravity has to offer them. Scientists and engineers have not been educated in the use

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[11] *Industry Week,* Mar. 3, 1980, p. 90.

of the microgravity environment and therefore may not investigate how the absence of gravity could aid their work. For their part, managers tend to focus on development time, risk, and potential returns on investment. As discussed above, space innovation does not seem attractive from this perspective. Although formal, quantitative project selection techniques can be used to project such factors as rates of return and pay-out periods, in the final analysis the decision to invest in new technology is a strategic choice that depends primarily on a corporate manager's business and technical judgments. The business community's lack of understanding about MPS makes it difficult for potential commercial space activities to compete with other, more traditional, investment opportunities.

The Scientific Community

NASA relies heavily on the scientific community, both industrial and university, to generate ideas for experiments and to provide direction and review for ongoing activities. NASA accepts unsolicited proposals from the scientific community for studies, theoretical and experimental research, or minor developments. Space flight experiments must be proposed in response to specific "Announcements of Opportunity" or "Dear Colleague" letters. NASA also sponsors science working groups to coordinate the interaction between NASA-funded investigators, scientists, engineers from universities, industry, and government labs and flight hardware contractors and NASA personnel.

NASA's initial enthusiasm for MPS research and its emphasis on the commercial potential of in-space processing found little immediate support in the scientific community. In 1978, NASA requested the Space Applications Board (SAB) of the National Research Council to review the MPS program. To accomplish this task, the National Research Council formed the Committee on Scientific and Technological Aspects of Materials Processing in Space (STAMPS). The STAMPS report concluded:[12]

> The early NASA program for processing materials in space has suffered from some poorly conceived and designed experiments, often done in crude apparatus, from which weak conclusions were drawn and, in some cases, overpublicized. Nevertheless, there is opportunity for meaningful science and technology developed from experiments in space **provided that problems proposed for investigation in space have from the outset a sound base in terrestrial science or technology and that the proposed experiments address scientific or technical problems and are not motivated primarily to take advantage of flight opportunities or capabilities of space facilities** (emphasis in original).

Since publication of the STAMPS report, NASA has worked to implement the report's recommendations. NASA requested the Universities Space Research Association (USRA) to assist in the organization and coordination of basic science working groups and to involve a larger segment of the scientific community in MPS research.[13] Since then, the USRA has sponsored science working groups, seminars, and workshops in the areas of bioprocessing, combustion sciences, containerless processing, fluids and transport phenomena, and solidification processes. Under NASA's direction, USRA has also established contacts with U.S. industry and various professional associations that share similar basic science interests.

The USRA working groups have also attempted to coordinate their activities with scientists from ESA and other nations interested in MPS. In 1983, USRA entered into an agreement with NASA and ESA to act as a liaison between the MPS science working groups of the two space agencies.[14] USRA has encouraged joint ventures between ESA and NASA principal investigators, and the sharing of experimental facilities.

[12] *Materials Processing in Space*, op. cit., p. 5.

[13] USRA is a private nonprofit corporation that was organized in 1969 by the National Academy of Sciences and is presently composed of 54 universities. It is chartered to provide a means through which universities and other research organizations may cooperate with one another, with the Government of the United States, and with other organizations toward the development of knowledge associated with space science and technology. USRA is further chartered to acquire, plan, construct, and operate laboratories and other facilities for research, development, and education associated with space science and technology.

[14] Hearings on Materials Processing in Space, Before the Subcommittee on Space Science and Applications of the House Committee on Science and Technology, 98th Cong., 1st sess., Statement of Dr. Guy Rindone, Universities Space Research Association, Sept. 14, 1983.

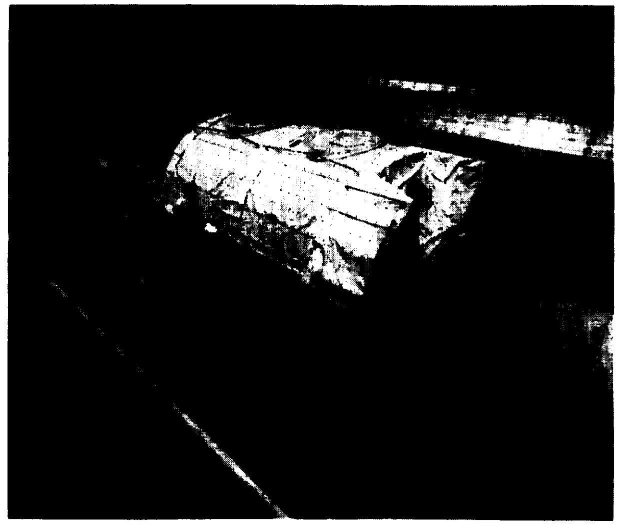
FOREIGN MPS ACTIVITIES

European Space Agency (ESA)

European interest in microgravity research began primarily as an outgrowth of ESA's commitment to Spacelab. Spacelab is ESA's largest cooperative project with NASA, involving European expenditures over the last 10 years of approximately $1 billion. ESA was responsible for designing and building Spacelab, and in December 1981, delivered to NASA, free of charge, the first flight unit. The first Spacelab mission flew in November 1983 and involved a joint European-American crew conducting a variety of test projects. Although West Germany has been the main financial contributor, providing over 50 percent of the budget, all ESA member states (except the Republic of Ireland and Sweden), and one of its associate member states (Austria) have participated in the Spacelab development program. The West German firm MBB/ERNO is the prime contractor for Spacelab; it was assisted in its development activities by some 40 other European companies. At the height of the development phase, an industrial work force of about 2,000 was employed on the program.[15]

Spacelab will provide opportunities to conduct space-based experimentation in both the physical and biological sciences. It consists of a pressurized module capable of being carried in the payload bay of the Space Shuttle and allowing experimenters to work at a variety of projects in a shirtsleeve environment. Additional pallets are also available which can be placed in the Shuttle bay to allow equipment to be exposed directly to the vacuum and radiation of space.

In early 1982, eight ESA member states agreed to undertake a Spacelab Follow-on Program.[16] The most important element of this program is the development of a European Retrievable Carrier (EURECA), to be launched and retrieved by the Space Shuttle. Funding for this program also covers the flight costs and development of the core payload for the first mission, which will concentrate on microgravity research. The first flight is scheduled for launch in April 1987 and retrieval in September 1987.



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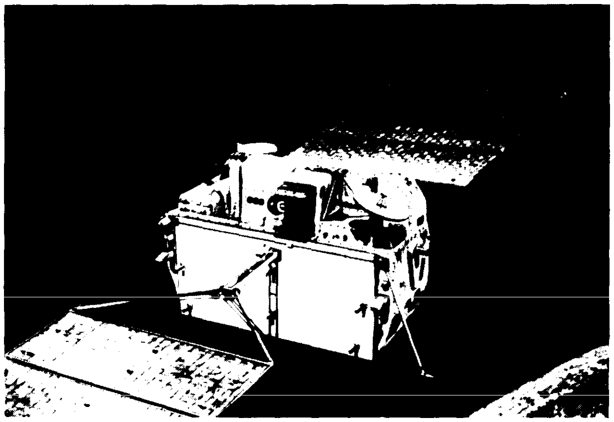
EURECA is a reusable payload carrier designed to carry a payload mass of up to 1,200 kg and to remain in orbit for 6 months. After deployment into space from the Shuttle, an on board propulsion unit will place the carrier into a higher orbit where the drag on its large solar arrays will be low. Once in its operational orbit, the payload will be switched on and operated by remote control. Although the experiments will be highly automated, they will nevertheless be monitored from the ground. By the end of its mission EURECA's orbit will have degenerated to the point where it can be recovered by the Shuttle. The spacecraft will then be brought back down to Earth, along with its payload equipment and processed material samples, for refurbishment for its next mission.

In addition to the Spacelab program, ESA, in January 1982, established its Microgravity Program to encourage basic MPS research (fig. 8-4). The experiments proposed to date can be divided into two main areas: life sciences, in which researchers can study the effects of reduced gravity on living organisms, including man; and ma-

[15] European Space Agency, *Europe Into Space*, Paris, January 1983, p. 36.

[16] They were Belgium, Denmark, Federal Republic of Germany, Italy, Spain, Switzerland, and the United Kingdom.



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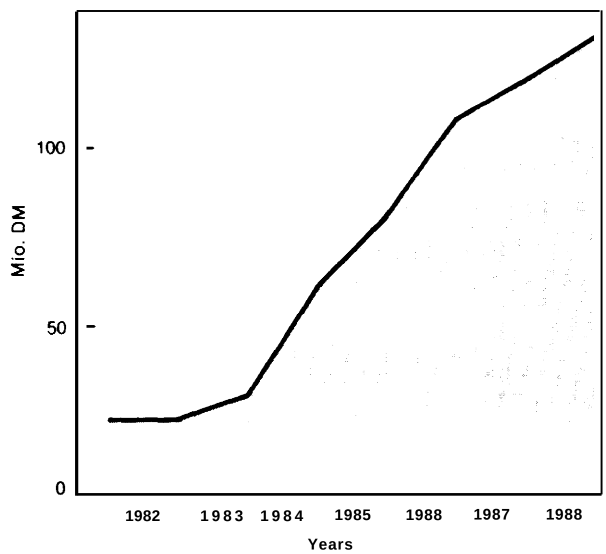
F gu e 8 4 ESA Budge o M c og a y Resea ch Program[a]



[a]June 1982 - 2.460DM . $1;U.N. Monthly Bulletin of Statistics, August 1982.
SOURCE: MBB/ERNO.

terial sciences, in which the behavior of fluids, crystals, glasses, and metallurgical systems can be studied. In order to meet these objectives, ESA has concentrated on four main program elements:

1. Sounding Rockets: ESA participates in TEXUS, the West German and Swedish sounding rocket program. It had a share of the payload on two flights each year since 1982, with further flights planned for the forthcoming years. Future ESA experiments on TEXUS will concentrate on the fields of metallurgy and fluid physics.[17]
2. **Biorack:** The Biorack is a multiuser experimental facility for investigating cell and molecular biology, botany, and radiobiology in the weightless environment of the Spacelab module. The Biorack consists of a "glovebox" for handling experiments, a cooler/freezer unit to protect specimens prior to launch and after landing, incubators, and a centrifuge to simulate gravity for reference purposes.[18] The firms MATRA, BTM, and Dornier have responsibility for developing the thermal conditioning units; Fokker is building the "glovebox;" and MBB/ERNO, with several subcontractors, is building the single rack equipment.[19] The Biorack will be flown on the West German D-1 Spacelab mission in 1985.
3. **Fluid Physics Module: Also designed to be flown in the Spacelab module is the Fluid Physics Module, which** will be used to study materials in suspended liquid form (floating zones) in the microgravity environment. A fluid physics module was flown on Spacelab-1 and an improved version is planned for the D-1 Spacelab flight in 1985.
4. Materials Sciences Double Rack: This microgravity research facility was developed by West Germany and flown on the first Spacelab mission. West Germany has since turned over responsibility for the Double Rack to ESA; it is scheduled to be reflown on the West German D-1 Spacelab mission.

Although classified as a Spacelab follow-on program, the first EURECA payload will be almost entirely devoted to material and life sciences and therefore will contribute considerably to ESA'S Microgravity Program.

Federal Republic of Germany

West Germany has an aggressive national MPS program and also conducts research with ESA or bilaterally with other countries. The Ministry for Research and Technology (BMFT) coordinates

[17]*ESA Annual Report*, 1982, p. 54.
[18]Ibid., p. 52.
[19]Ibid.

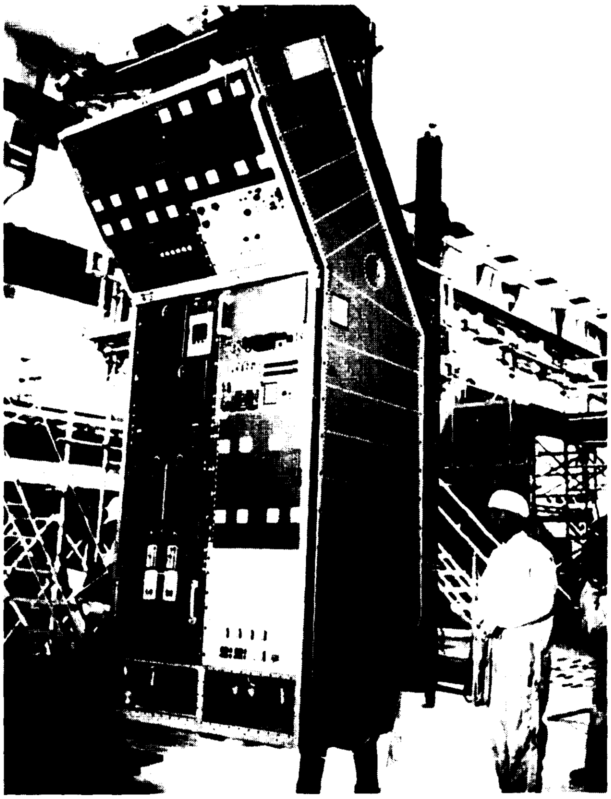


Photo credit: National Aeronautics and Space Administration

Europeandeveloped life sciences mini lab for Spacelab.

and funds most West German R&D efforts. Projects are managed by the German Aerospace Research Establishment (DFVLR), which directs government engineering and test centers, and by the German Research Association (DFG), a self-governing organization that allocates funds from various public and private sources to universities and scientific societies.[20] West Germany's major aerospace firms also play a key role in initiating and funding research projects.

Germany has placed a strong emphasis on materials science and life science experiments in its space program. Since the West German firm MBB/ERNO is the prime contractor for Spacelab, and West Germany is the major financial contributor (54.9 percent), German interest in Spacelab exploitation has been high. In addition, chemicals and materials processing have traditionally been areas of German technical and industrial leadership.

The Ministry for Research and Technology provided approximately $50 million for MPS work from 1978 to 1981 and is authorized to spend about $100 million more between 1982 and 1985 (fig. 8-5). These figures represent the total West German federal commitment to MPS research. They do not include the contributions of private research programs, other related space activities, or terrestrial materials research. Over the past several years, the West German Government has endeavored to shift a part of the practical research burden to other sources, principally commercial and industrial organizations, and to use available government funds to sustain basic research programs.

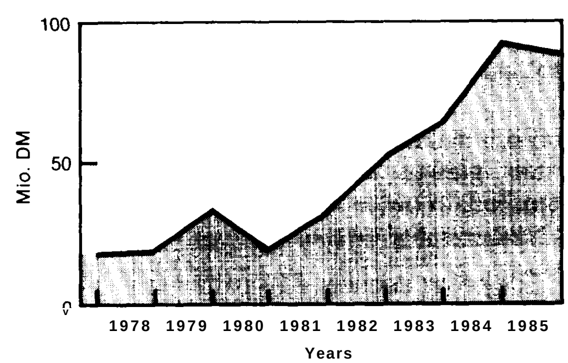
The German MPS program is intended to meet the as-yet largely undefined needs of the user community by conducting a wide variety of basic research projects. The ultimate goal of government support is substantial involvement of West German industry in such areas as chemistry, process technology, metals, composite materials, and crystals.[21]

Early West German MPS experiments were carried on the 1975 Apollo-Soyuz manned mission.

[20] " Review of National and Cooperative Space Activities for the Calendar Year 1980," UNCOPUOS, A/AC.105/286/Add.1., Feb. 19, 1981, pp. 34-35.

[21] "Commercialization of Materials Processing and Manufacturing in Space, " TRW, Defense and Space Systems Group, Apr. 14, 1981, p. 26.

Figure 8-5.—Budget for Microgravity Research Program'



'June 1982- 2.460DM = 1$; UN. Monthly Bulletin of Statistics, August 1982.

SOURCE: MBB/ERNO.

Several methods are now used: suborbital sounding rockets, small self-contained payload packages (so-called "getaway specials") attached to the space Shuttle, and full-scale Spacelab missions. The Germans are examining future flight opportunities using free-flying automatic experimental units for longer periods of time than can be attained with the present Shuttle/Spacelab system. Primary elements of the West German MPS Program are:[22]

- **TEXUS (technological experiments u rider microgravity): Certain experiments are being flight-tested using British-built Skylark sounding rockets. Since 1977, TEXUS launches** have flown over 100 MPS experiments. The program presently calls for two TEXUS launches per year. A number of experimental facilities are already available to users, and more will be added as demand increases. The TEXUS program began as a cooperative project with Sweden, using the Kiruna range as a launch site; since 1982, ESA has also participated in TEXUS. West German experiments have also flown on U.S. SPAR sounding rockets.
- **MAUS** (autonomous materials science experiments in microgravity): The MAUS program employs standardized containers similar to those NASA makes available to its "Get-Away-Special" (GAS) customers and instruments derived from the TEXUS program to conduct small MPS experiments on the Shuttle. The BMFT has paid for 25 GAS flights; one was used on STS-5 and the rest will be used at a rate of 2 to 4 a year over the coming years. The BMFT has also purchased six GAS canisters which they modified for use on other carriers. On STS-7, three MAUS experiments in GAS canisters were attached to the OSTA-2 structure, and two experiments mounted on the SPAS structure. Two further MAUS experiments were flown on SPAS during the SPAS reflight mission, STS-11. The West German companies MBB/ERNO, Kaiser-Threde, and Dornier have reserved GAS flight opportunities. In addition, the West German Oberth Society, which promotes space research, has reserved a flight.
- **Spacelab: West Germany is supporting major experiments on Spacelab and was responsible for the development of the Materials Science Double Rack (MSDR), a materials processing laboratory. A West German-sponsored Spacelab mission,** D-1, is scheduled for 1985. The D-1 will carry experiments for the West German Space Program, ESA, France, Italy, and NASA. Informations from all the D-1 experiments, except NAVEX, a proprietary communication and navigation experiment, will be freely disseminated. Planning has already begun for a D-2 mission which will be devoted primarily to microgravity research.
- **SPAS (Shuttle pallet satellite):** SPAS is a carrier which may be operated either in the Shuttle bay or in a free-flying mode. SPAS was developed by MBB/ERNO as a com-

Photo credit: National Aeronautics and Space Administration

View of SPAS (Shuttle Pallet Satellite) prior to flight on STS-7. The payload consists of a beam like structure which fits across the cargo bay and contains both self-contained power and attitude control systems which allow it to be deployed and retrieved by the orbiter's remote manipulator arm.

[22] Gottfried Greger, "The German Material Processing in Space Activities, " paper presented at The Twentieth Goddard Memorial Symposium, NASA Goddard Space Flight Center, Mar. 17-18, 1982.

pany-funded venture with financial assistance from the BMFT. It is the first of a new generation of free-flyers designed to take advantage of the present and future needs for long-duration facilities in space. SPAS is able to supply limited power, cooling, and utilities to a payload. It currently has no propulsion system but has a modest station-keeping capability. The first SPAS was launched on STS-7 to test the deployment ability of the Shuttle remote manipulator. SPAS was reflown but not deployed on STS-11 in February 1984.

- EURECA (European retrievable carrier): Although it is an ESA project, the prime contractor for the EURECA is MBB/ERNO and West Germany will supply the major share of the funding. EURECA is based on the SPAS structural concept but will have greater payload capacity, power, cooling, and a propulsion system.

France

French MPS activities are modest in scope, with a budget of approximately $1 million to $2 miliion per year. Bilateral materiais processing experiments have been conducted with West Germany and the U.S.S.R. A France-Soviet crystal growth and solidification experiment was carried out aboard the Soviet manned laboratory, Salyut-6, several more experiments were conducted on Salyut-7 and future cooperative MPS research is anticipated. French experiments on crystal growth and the dynamics of metal alloy solidification were conducted on Spacelab-1. in addition, the French Atomic Energy Commission (CENG) and NASA are planning a cooperative project called MEPHISTO (Materiel pour l'Etude des PhEnomenes Interessant de la Solidification sur Terre et en Orbite).[23] Through this project the CENG is developing a metallurgical furnace to be used in the NASA MPS program. CNES has also requested to fly, on a reimbursable basis, a crystal growth experiment on Spacelab-3.

In general, the French effort is smaller and more research-oriented than the West German. CNES has studied since 1978 an ambitious program called "Solaris," an unmanned orbital space station which would be able to conduct MPS experiments, perhaps on a commercial basis (fig. 8-6). Solaris could be orbited by an Ariane-4 launcher, offer about 1s kilowatts of power and in-orbit data processing, and operate for up to 15 years. There has been no significant movement to pursue the Solaris concept. This seems to be the result of the French preoccupation with Ariane development, the belief that MPS does not offer near-term commercial opportunities, and a recent change in French policy that acknowledges the usefulness of man in space for some types of experimentation. Recent French interest in the Hermes (see ch. 5) manned, reusable space plane, would seem to confirm this trend. The Hermes would likely be useful for MPS research and for launching and recovering free-flying platforms.

It is conceivable that Hermes or Solaris might be accepted as a major project for ESA during the 1990s, thereby spreading the cost and stimulating MPS research activities in a number of member countries not presently pursuing such investigation. These projects not only create increased demand for Ariane launchers, but offer European alternatives to participation in a U. S.-developed space station.

Japan

Japanese MPS activities began in 1973 with an experiment flown on Skylab. Further research is being conducted on the Space Shuttle, Spacelab and the TT-500-A, a Japanese suborbital rocket. The TT-500-A first flew in September 1980; since that time, five additional flights have been accomplished. The Japanese have also reserved one-half of a Spacelab flight in 1988 (the First Materials Processing Test, or FMPT). Project selection and hardware development for this flight are currently under way; at present, [45] materials processing experiments and 17 life science experiments are plan ned.[24]

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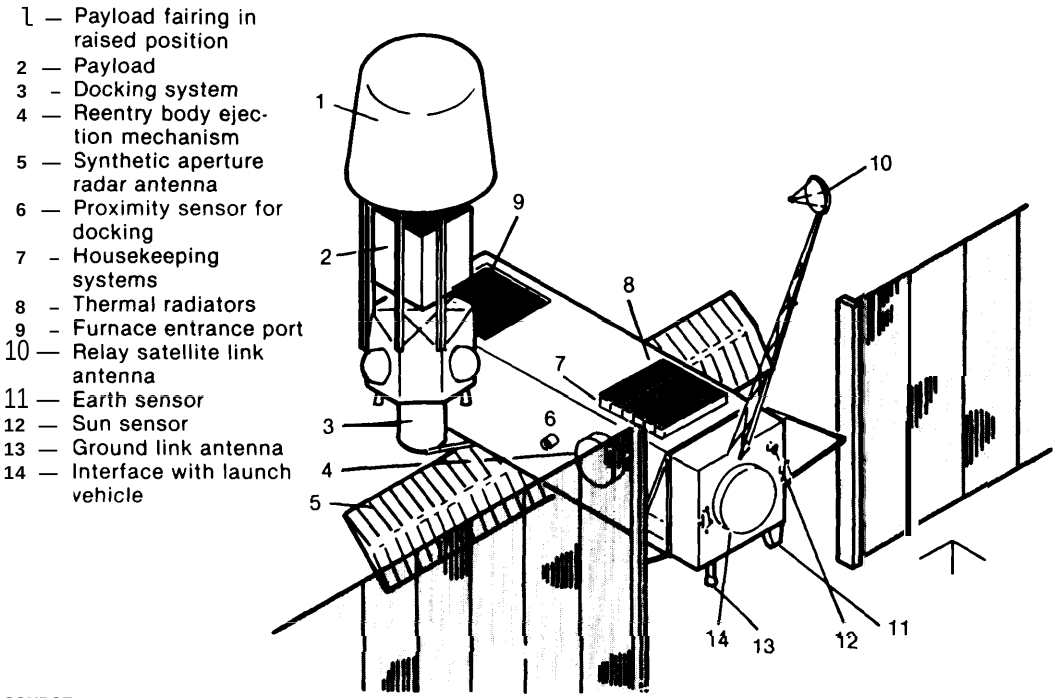
[23] J. J. Favier, Y. Malmejac, et al., "MEPHISTO: Research Equipment for the Study of Solid/Liquid Interface Destabilization in Metal Alloys, " 33d Congress of the International Astronautical Federation, Sept. 27-Oct. 2, 1982, Paris, France.

[24] A. Sawaoka, "Japanese Efforts Towards Materials Processing in Space, " *Manufacturing in Space,* L. Kops (cd.), The Winter Annual Meeting of the American Society of Mechanical Engineers, Boston, MA, Nov. 13-18, 1983, PED-Vol 11, p. 40.

Figure 8-6.—Sketch of the Proposed Solaris Orbital Station With (top centre) One Payload Recovery Capsule Being Ejected for Reentry



SOURCE: CNES.

In 1982, Japan's Council for Science and Technology advised the Prime Minister that MPS was one of the scientific fields meriting urgent research attention.[25] The Science and Technology Agency (STA) was then given responsibility for organizing a 5-year research program. The first 2 years are to be spent conducting basic and theoretical research; the third and fourth years are reserved for terrestrial experimentation to result in the development of the flight hardware for the FMPT, which would occur in the fifth year. Although the STA has primary responsibility for the Japanese MPS program, a committee has been established to coordinate STA activities with those of other government agencies (e.g., NASDA), universities, and the private sector.

The Japanese have no current plans to build a separate platform, such as Solaris, or a free-flying carrier, such as SPAS or EURECA. However, Japan has expressed a willingness to cooperate with NASA on the development of a space station.

[25] Ibid., p. 41

Soviet Union

MPS experiments have had a high priority on recent Soviet space flights, especially aboard the Salyut-6 and Salyut-7 orbiting laboratories.[26] Research has been conducted in both materials processing and the life sciences. Two furnaces, the Splav-01 and the Kristall, have been used to conduct experiments on semiconductors, crystal growth, alloys, glasses, and metal oxides. Samples have been returned to Earth for detailed analysis. Approximately 300 to 350 Soviet scientists are reported to be actively engaged in materials research related to space processing.[27]

[26] B. Belitsky, "Soviet Manned Space Flight 20 Years On," *Spaceflight*, vol. 23, No. 5, May 1981, pp. 154-155.

[27] "U.S. Must Spend More to Maintain Lead in Space Technology," GAO-FGMSD-80-32 (Washington, DC: U.S. General Accounting Office, Jan. 31, 1980), p. 21,

The Soviets have also conducted research into electrophoretic separation techniques in space. Reports indicate that these experiments are similar to those presently being conducted by NASA and McDonnell Douglas.[28]

[28] T. Chesanova, *Space Biotechnology Experiment Furthers Work on Superpure Vaccines,* **Leningradskaya Pravda, May 22, 1983, No., 119, p. 4, COl. 1-3. (Abstract: Daily SNAP, June 8, 1983).**

MPS PRODUCTS, SERVICES, AND EQUIPMENT

It is impossible to make accurate predictions about the future size and vitality of the markets for MPS products, services, and equipment. The potential for the development of an MPS industry in the United States and elsewhere is dependent on a variety of factors including continued government-funded basic research, availability of reliable low-cost space transportation, access to medium- or long-term MPS facilities such as free-flyers or a space station, competition from terrestrial processes, and serendipitous discovery of commercially viable MPS products.

Other countries have demonstrated considerable interest in MPS research and hardware development; this could eventually translate into competition for the U.S. private sector. The U.S. commitment to development of an MPS science community, the existence of the Shuttle, and NASA's encouragement of commercial space activities give the United States important advantages. These advantages will diminish over the next several decades as access to space becomes more routine and the understanding of the advantages and limitations of microgravity technology become more widely known.

Potential MPS Products

Basic MPS research in the United States and elsewhere has, to date, produced only one marketable product.[29] As knowledge of the microgravity environment increases, it is possible that major unforeseen scientific advances as important as penicillin or microcircuits may result. Such advances could conceivably revolutionize existing terrestrial markets and create entirely new markets. Just as it was difficult to assess the importance of the first computer or airplane to the economy of the United States, it is difficult to estimate the future role for MPS products. On the other hand, not all new technologies can be successfully commercialized. Nuclear power and supersonic transportation are examples of technologies which offered great promise but have had limited commercial success.

The most likely candidates for commercialization now appear to be certain pharmaceutical products and crystals for use in the electronics industry.

Pharmaceuticals

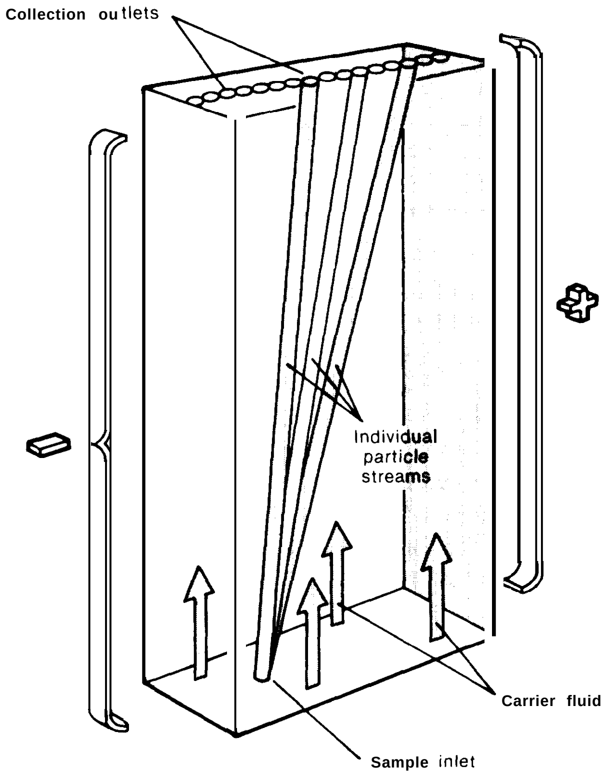
The separation of biological materials using techniques such as electrophoresis can be significantly enhanced in the near-zero gravity environment of space. Electrophoresis is the movement of particles in solution when they are placed under the influence of an electric field (fig. 8-7); because particles have different charges and sizes, they will move at different speeds away from one electrode towards another with an opposite charge. This natural movement allows the segregation and isolation of different components of a mixture.[30] On Earth, gravity reduces both the usable concentration and quantity of the material being separated. Tests performed on STS-4 (June 1983) as part of the MDAC/NASA Joint Endeavor Agreement demonstrated 125 times greater concentrations and 463 times greater quantities than could be obtained from equivalent ground-based units.[31]

[29] The product is monodisperse latex spheres. It was manufactured by Particle Technologies in a Getaway Special Canister. The spheres are used in various medical calibration techniques.

[30] See generally, D. W. Richman, "EOS-Electrophoresis Operations in Space—A Promising New Era of Business in Space," *Manufacturing in Space,* L. Kops (cd.), The Winter Annual Meeting of the American Society of Mechanical Engineers, Boston, MA, Nov. 13-18, 1983.

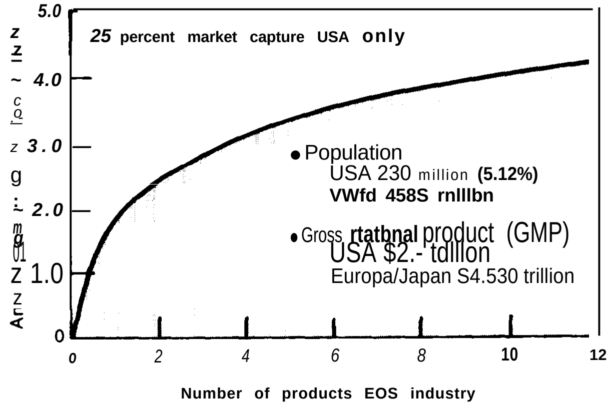
[31] Ibid., p. 141.

Figure 8-7.—Continuous Flow Electrophoresis



Continuous flow electrophoresis separates the sample into individual particle streams.
SOURCE: McDonnell Douglas.

Figure 8-8.-Annual Market Potential for Electrophoresis



SOURCE: McDonnell Douglas.

Before signing its JEA with NASA, MDAC–in conjunction with its industrial partner-Ortho Pharmaceuticals–conducted a market analysis to determine potential commercial applications for electrophoresis. This analysis led to the identification of 12 pharmaceutical products that might profitably be produced in space. MDAC estimated the annual domestic market for these products to be in excess of $7 billion (fig. 8-8).[32] According to MDAC, these are conservative estimates based on the capture of 25 percent of the projected annual domestic market of each product.

Crystals

Semiconductor device technology requires reasonably priced, single-crystal wafers that meet specifications for crystalline and chemical perfection.[33] Although silicon remains the material of primary interest to the electronics industry, attention has also been directed towards starting materials such as gallium-arsenide (GaAs) and mercury-cadmium-telluride (HgCdTe). Today, the chemical and crystalline imperfections of these materials make them only marginally suitable for device fabrication. It is possible that significant improvements in the properties and yields of semiconductor materials can be achieved by producing them in space.

NASA researchers have performed a number of experiments on these materials and NASA has entered into a JEA with Microgravity Research Associates to investigate the commercial production of GaAs crystals. High-quality GaAs crystals might be used for:[34]

- very high-speed microwave circuits (1 O to 150 gHz);
- radiation-resistant, high-speed signal processing on missiles;
- high-speed signal processing with integral lasers for readout through fiber optics; and
- semiconductor radar arrays on airplanes and satellites.

[32] "Space Station Needs, Attributes, and Architectural Options," McDonnell Douglas Astronautics Co., Huntington Beach, CA, NASA contract NASW-3687, Task 1, April 1983, pp. 36-39.

[33] A. F. Witt, "The Impact of Space Research on Semiconductor Crystal Growth Technology," *Manufacturing in Space*, L. Kops (cd.), The Winter Annual Meeting of the American Society of Mechanical Engineers, Boston, MA, Nov. 13-18, 1983, p. 43.

[34] "Commercial Utilization of a Space Station: New Business Opportunities" (Downey, CA: Rockwell International, SSD 83-0046, March 1983), pp. V-2-V-16.

The primary initial purchasers of space-produced GaAs crystals would be the military; it is possible, though not certain, that the civilian electronics industry would also be a major purchaser of GaAs crystals. Figure 8-9 illustrates the potential future demand for space-produced GaAs crystals; because of the complex and rapidly changing nature of the electronics industry, and the potential for competition from terrestrially manufactured GaAs crystals, no attempt is made here to assess the accuracy of the figures presented.

Potential MPS Services and Equipment

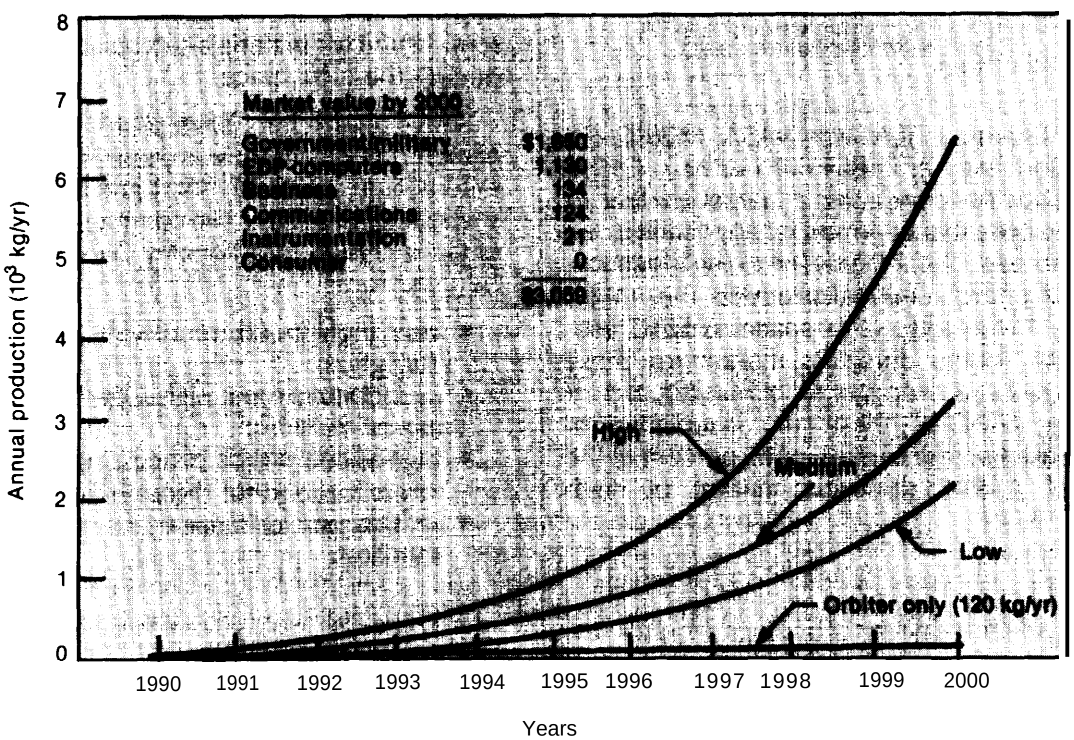
U.S. Activities

Recent experience with NASA and private sector MPS experiments has revealed that:

- There is a weak but discernible demand for reasonably priced research facilities for in-space experiments; this demand may expand as the applications for in-space research become more widely known.
- There is a need for MPS equipment such as carriers and furnaces, both for specific applications and for basic research.
- At present, the long lead time between conceptualization and flight of an experiment and the cost of custom-fitting each experiment into the Shuttle are barriers to greater use of the Shuttle as a research tool.

These findings indicate that there may be opportunities for the private sector profitably to offer MPS services and equipment. Most of the Technical Exchange Agreements (TEAs, discussed above) between NASA and industry have been designed to gain a better understanding of terrestrial phenomena. John Deere & Co. entered into a TEA in 1981 to study the solidification of cast iron. The purpose of this research was to gain a better understanding of how the graphite formation of cast iron influences the metal's properties.

Figure 8-9.—Demand for Space-Produced GaAs (millions of dollars)



SOURCE: McDonnell Douglas.

INCO Research & Development Center, Inc., signed a TEA with NASA in 1982 to investigate the basic properties of electroplating. Similarly, Dupont entered into a TEA in 1982 to explore the catalytic properties of alloys. Such activities indicate a potentially broad industrial interest in obtaining low-cost experimental data. This opens up a number of opportunities for private sector operation of service-oriented activities, such as the provision of generic test equipment, common-use buses to fly small user-specific experiments, and integration services to reduce the complexity of NASA/private sector interaction.

If one accepts this interim goal, the question then becomes how best to pursue it. One way is to focus on reducing the cost of experimental results per sample, thereby increasing both the pool of potential users and the amount of information obtained over a given period of time. This basic approach was unsuccessfully attempted in GTI's Joint Endeavor Agreement with NASA. GTI had intended to fly on the Shuttle a metallurgical research furnace designed to accommodate a large number of experimental samples. Under the terms of the JEA, the furnace was to have been flown four times at NASA's expense in order to assess its commercial viability. GTI's clients would have had the opportunity to obtain data from samples of their choice at a fraction of the cost of fielding their own instruments (discussed above).

One U.S. firm, Instrumentation Technology Associates, Inc. (ITA), has announced that it wishes to enter the MPS equipment market by selling standardized experimental modules which would fit into NASA's GAS canister. ITA plans to offer customers the option of the module structure by itself, a complete module with experiment avionics and lease of a complete module for a flight, or rental space inside a canister flown by ITA.[35]

Another private firm is investigating the practicality of a fee-for-service laboratory to operate in conjunction with the U.S. space station. Such a laboratory would allow customers to buy a number of days or hours of time to perform experiments. It would eliminate the need for frequent Shuttle flights and would allow a degree of interaction between scientist and experiment that is not now possible.[36]

JEA proposals submitted in 1983 to NASA by Ball Aerospace and Teledyne Brown Engineering suggested another approach to MPS service development. Under each of these proposals, the private sector participant would provide a carrier to fit in the cargo bay of the Shuttle. These carriers would supply utilities such as power, cooling, and telemetry; NASA payloads and payloads of opportunity would be attached to the carrier at any of a number of common use "ports."

Each of these JEAs requested the opportunity to assume the marketing and integration functions for all future MPS experimental payloads. The integration (preparation of payload and placement into Shuttle) of MPS payloads is considered essential to each of these JEAs, since this would provide an assured source of income while building the commercial market for this service. Integration for MPS payloads is currently being conducted under contract for NASA by Teledyne Brown Engineering.

NASA's reluctance to decide between the Ball and Teledyne proposals was based in part on the applicants' request that NASA experiments be flown on commercial carriers, and in part on NASA's interest in developing what eventually became the Hitchhiker program.

NASA's JEA with Fairchild Industries is another opportunity for a private sector-provided MPS service. The Shuttle and the Shuttle/Spacelab combination have three important limitations:

1. The movements of crew members aboard the Shuttle cause micro-accelerations which can interfere with results of certain MPS experiments.
2. Shuttle flight duration is only 10 days or less, and many experiments will require longer periods of microgravity.
3. The Shuttle does not have adequate power for certain MPS applications.

[35] *Aviation Week and Space Technology*, June 25, 1984.

[36] "Booz-Allen, Weinberg Report on Space-Business Prospects," *Space Business News*, Jan. 2, 1984, p. 4.

Fairchild plans to develop a small platform called "Leasecraft" which could provide an alternative to Shuttle/Spacelab activities (fig. 8-10). Leasecraft is a spacecraft bus designed to provide services such as power, communications, data handling, and propulsion for attitude control. The customer supplies the payload—in this case, an MPS experiment or production facility–which is then attached to the Leasecraft. The Leasecraft is then launched aboard the Shuttle and transferred to a free-flying mode for an indefinite amount of time. The Shuttle would service the Leasecraft, supplying it with new feedstock and returning processed materials to Earth. Leasecraft is not designed to be returned to Earth to be refitted with new cargo, as is the EURECA or SPAS, nor is it designed to operate in the Shuttle bay as would the carriers proposed by Ball and Teledyne.

Fairchild proposes to provide customers with a turnkey operation. It would handle all arrangements for launch, servicing, and return of processed materials from space. The customer would not own, but rather would lease this spacecraft. It is possible that McDonnell Douglas' electrophoresis operations will provide the first customer for the Leasecraft.

Foreign Activities

West German and ESA activities in the development of "carriers" and "free-flyers" allow them to offer commercial MPS services similar to those proposed by Ball, Teledyne, and Fairchild. The West German SPAS and ESA'S EURECA reflect an important European commitment to the development of space facilities that are Shuttle-compatible yet reasonably independent of U.S. budgetary and political influence.

When MBB began developing the SPAS, it hoped, like Fairchild, to offer a turnkey service to customers willing to pay a broker to provide the payload structure and Shuttle integration and to do the necessary flight negotiations with NASA. In addition to MPS payloads, MBB also expects to use the SPAS as a bus for national and European scientific, application, and communication satellites.

When NASA began to consider developing a carrier that could fly on short-notice, space-available basis (a concept which has had several names and is currently known as "Hitchhiker"), MBB/ERNO informally proposed the use of SPAS. NASA's indecision regarding its own carrier needs, the JEA proposals of Teledyne and Ball, and a general reluctance to engage in quasi-commercial activities with foreign partners have prevented a positive response to this suggestion.

The MBB/ERNO "payload support system" (PASS) has already been flown eight times on West German MAUS missions. The PASS fits inside a standard NASA GAS canister and includes an experiment mounting structure, main power battery, experimental control units, housekeeping sensors, and data evaluation units. MBB/ERNO is now marketing the standardized support system developed for the MAUS program to NASA get-away-special customers.[37]

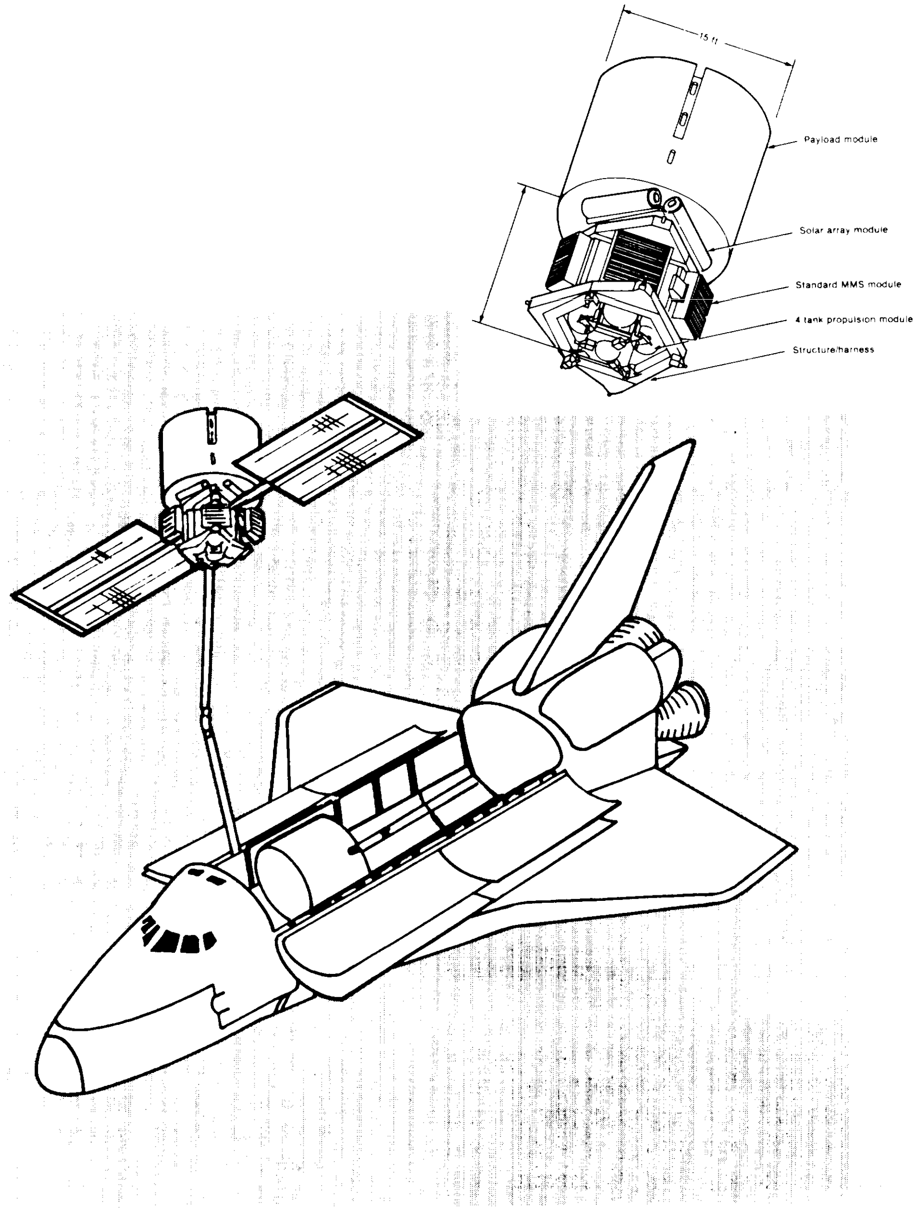
The ESA project, EURECA, although smaller and less powerful than Fairchild's Leasecraft, would offer similar utilities (e.g., power, cooling, propulsion, attitude control, and telemetry). However, Fairchild will be developing only the spacecraft bus (the Leasecraft); ESA, in addition to developing the bus (EURECA) will also provide multi use MPS hardware. The first EURECA flight, planned for October 1987, will carry a payload of six experimental facilities, three of which were developed for Spacelab.[38]

These instruments and the majority of the initial EURECA missions are oriented toward building basic scientific knowledge of physical phenomena in microgravity. Applications experiments are now being left to various national programs working in association with private firms. ESA would like to fly the EURECA about once every 2 years, and is discussing with NASA a cooperative arrangement to provide sufficient ex-

[37] "MBB Sells GAS Payload Support," *Space Business News,* Jan. 30, 1984, p. 8.

[38] 1) An automatic mono-ellipsoidal mirror furnace for crystal growth experiments (developed for Spacelab); 2) a solution-growth facility for diffusion-controlled crystal growth (developed for Spacelab); 3) a protein crystallization facility (developed for Spacelab); 4) a multifurnace assembly; 5) an automatic gradient-heating facility; and 6) a multiuser life-sciences facility.

Figure 8-10.— Leasecraft Baseline Concept



Fairchild Leasecraft satellite with a McDonnell Douglas biological processing unit is grappled here by the manipulator arm. The barrel-shaped resupply module on top containing processed material will be removed and replaced by the new module in the payload bay that contains raw biological material for processing.

SOURCE: Fairchild Space and Electronics Co.

periments and funding to maintain this level of activity.[39] ESA is also investigating the potential for commercial use of EURECA and has considered transferring the responsibilities for the carrier to a private firm.[40]

The primary buyers of carriers, free-flyers, and other MPS equipment are government space agencies such as NASA, DFVLR, and ESA. The sellers in this market are, for the most part, aerospace corporations working under contract for national space agencies. At present, most firms involved in MPS research, such as MDAC, 3M, and MRA in the United States and MBB/ERNO in West Germany, have designed and built their own test equipment.

The vitality of a future market in MPS equipment will depend on developments in commercial products and services. For example, should McDonnell Douglas develop a pharmaceutical which can be profitably produced in space, it would be necessary to graduate from Shuttle operations to a free-flyer. MDAC estimates that it might need anywhere from *8* to 14 free-flyers to engage in a successful commercial venture. It has considered the Fairchild Leasecraft, a Hughes-designed free-flyer, MBB's SPAS, and the EURECA. MDAC has also considered developing and building its own free-flyer. A similar scenario can be imagined for any of the proposed space products discussed above, all of which would need more than the Shuttle to engage in successful commercial operations.

The demand for Shuttle-compatible carriers and related experimental equipment will most likely increase steadily throughout the decade, The percentage of this equipment which is available commercially as opposed to through government space agencies will depend on the success of current and future private sector proposals to conduct the integration and marketing of experimental services.

Development of the SPAS and ESA commitment to EURECA ensure at least a limited European presence in the international MPS equipment market. The extent of this presence is dependent on:

- **Political considerations: Should** ESA adopt a "buy European" attitude towards MPS research, it is conceivable that EURECA could become the carrier of choice for all European MPS experiments.
- **Technical considerations: Commercial** MPS operations will have specific needs for power, telemetry, and other vital utilities. McDonnell Douglas has indicated that, as presently configured, neither the existing SPAS nor the proposed EURECA could meet its power demands. The Fairchild Leasecraft, if developed, would seem to be able to meet these needs. European participation in the future MPS equipment market will be based, in part, on the ability to compete technically with the U.S. private sector.
- **Market considerations: To date, Fairchild industries has been unable to attract customers to its Leasecraft concept. It is possible that it will be many years before there is a strong demand** for commercial MPS production equipment. The EURECA'S ability to fly numerous small payloads and the existence of multiuse experimental equipment may make it the carrier of choice for conducting precommercial flight tests.
- **Financial considerations: Assuming a rough technical equivalence between U.S. and** European MPS equipment, competition will be based on cost. This may be significantly influenced by direct or indirect government subsidies. Such subsidies may be the incidental result of government R&D policies or the direct result of a policy to promote the sale of this equipment.
- **U.S. domestic policy:** The Shuttle is, at present, the primary means by which to conduct MPS research and manufacturing. The Europeans are therefore subject to U.S. policy decisions regarding access to and cost of Shuttle services. Unless Europe develops an alternative to the Shuttle for MPS research (e.g., the Hermes vehicle), the commercial success of European MPS endeavors may depend on U.S. domestic space transportation policies. It is important to note that in other important space technologies (space transportation, communication satellites, and remote sensing) the Europeans have chosen not to rely exclusively on U.S. technology.

[39] J. M. Lenorovitz, **"ESA Offers EURECA Platform for Shuttle,"** *Aviation Week and Space Technology,* **Oct.** *24, 1983,* **p.** *75.*

[40] **1 bid,**

COOPERATION IN MPS

There is substantial foreign interest in microgravity research. Since the United States controls the Shuttle, Spacelab, and other hardware essential to this research, it is a desirable partner for cooperation. It is important to examine the value of such cooperation to the U.S. space program, and, more generally, to long-term commercial and foreign policy interests.

Advancement of Science

The primary reason for pursuing international cooperation in MPS is to advance the microgravity sciences. Since NASA was founded it has pursued a vigorous program of international cooperation in the space sciences.[41] Recently, as missions have become more complex and expensive, and therefore more infrequent, a broad international interest in space science has allowed important scientific work to go forward which could not have been done by the United States alone. As the space programs of the Europeans and Japanese continue to grow in size and sophistication, so will the importance of international cooperation in the space sciences.

Shuttle Mission 7 provided an excellent example of international cooperation in MPS research.[42] On this mission, NASA entered into an agreement with MBB/ERNO, a private West German firm, to use the SPAS to test the Canadian remote manipulator system. Although NASA and MBB entered into a formal contract for reimbursement for the flight of the SPAS, the cost was discounted to reflect the value to NASA of having the SPAS as a test article. Also on STS-7, three MAUS units were flown as a part of an experiment by NASA's Office of Space and Terrestrial Applications (OSTA-2). NASA and BMFT agreed that the OSTA-2 flight opportunity would be matched by the reflight of the Materials Experiment Assembly (MEA) on the West German D-1 Spacelab mission. In both instances, flights were arranged on a "no exchange of funds" basis.

Foreign Policy

Development of space technology is a demanding and highly visible undertaking in which nations have traditionally invested substantial amounts of financial and political capital. MPS is certainly no exception to this general rule. The potential benefits of cooperative MPS research are not limited to such tangible items as monetary return or technical advances, but include such intangibles as national prestige and the desirability of maintaining stable relationships with other countries. **Decisions about the level of international cooperation that NASA wishes to pursue will undoubtedly influence the investments and programs of other countries. To the extent that NASA's decisions have a negative effect on the space programs of other countries, they may be less willing to support U.S. foreign policy objectives in space and elsewhere.**

With the exception of terrestrial facilities and sounding rockets, the Shuttle is the only non-Soviet means available for the conduct of microgravity investigations. As a result, foreign space hardware has been designed *to* take advantage of the special characteristics of the Shuttle. Such hardware includes the ESA Spacelab and all of its laboratory equipment, the future EURECA, West Germany's SPAS and MA US canisters, and France's MEPHISTO furnace. Future decisions regarding Shuttle and Spacelab pricing and availability should be made with the understanding that other countries have also made substantial economic and political investments in this technology.

Foreign Sale of U.S. Technology

Until recently, the United States held a virtual monopoly on the sale of space services and equipment. Now, even though the demand for such products is increasing, so is the number of capable suppliers. It is, therefore, important to examine what role international cooperation might play in the promotion of these U.S. space goods and services.

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[41] See generally: U.S. Congress, Office of Technology Assessment, *UNISPACE '82: A Context for International Cooperation and Competition,* OTA-TM-ISC-26 (Washington, DC: U.S. Government Printing Office, March 1983), app. B.

[42] Craig Covault, "Shuttle 7 to Carry Multinational Payload," *Aviation Week and Space Technology,* May 6, 1983, pp. 52-57.

As a result of the unique characteristics of the Shuttle and past NASA cooperative projects, most foreign MPS research will rely in some part on U.S. facilities. It might be possible to translate this reliance into an economic advantage for the United States. To the extent that foreign MPS programs remain dependent on the Shuttle, Shuttle use is expanded and the cost of similar U.S. projects is reduced. **Policies that discourage foreign use of the Shuttle by charging high prices for its use or limiting access serve to increase the rate of speed at which alternatives to the Shuttle will be developed.**

Currently NASA and the private sector have discussed the development of a range of MPS hardware, including carriers, experimental equipment such as furnaces, and free-flyers. Cooperative programs that encourage the use of U.S. hardware increase the potential for eventual sales of such hardware.

Cost Savings

As a result of their interest in Spacelab and in MPS generally, the European countries and Japan have developed, or are in the process of developing, valuable experimental hardware. Much of it is designed to be reflown and can support a number of experiments. **In recent years, NASA resources have been directed primarily to the completion and flight testing of the Shuttle. As a result, in select areas of MPS research the United States is behind in the development of useful hardware.** This fact has caused NASA to suggest the creation of an International Microgravity Lab (IML) to allow the international sharing of MPS flight equipment,

The IML concept, developed by NASA's Spacelab Flight Division, envisions that the United States can reduce the cost of Shuttle flights and the "rent" of Spacelab as a means to gain access to European hardware. Discussions have focused on the life science and materials hardware (primarily the ESA Biorack and West Germany's Materials Science Double Rack), though the free-flyers, SPAS and EURECA may eventually enter the negotiations. The Europeans have responded favorably to initial NASA inquiries, and there are feasibility studies under way on both sides of the Atlantic.

The assumption underlying the IML is that most current MPS research seeks scientific knowledge about the microgravity environment. Given this common goal, the IML would reduce duplicative activities, allow cost sharing—particularly with regard to experimental hardware–and encourage use of the Spacelab and the creative interchange of ideas. Whether or not the IML is approved, it raises an important issue. **Unless the United States is prepared to commit more of its public and private resources to space than it does now, it cannot hope to maintain preeminence in all aspects of MPS technology. Given the likely constraints on the Federal budget, international cooperation will play an increasingly important part in future** MPS **projects.**

POLICY OPTIONS

In the near future, the United States will have to make important decisions concerning the proper roles of international cooperation and competition in the microgravity sciences. So **far, commercial sales in MPS have been limited to the hardware supplied to NASA and foreign space agencies for experimental purposes. Competition between the U.S. private sector and foreign suppliers**—either private sector or government—does not yet exist. However, the MPS research of ESA, and of France, West Germany, and Japan, clearly indicates the intention to pursue potential commercial MPS applications. It is important that the **U.S. Government begin to consider whether, and** to what extent, it will support the commercial interests of the U.S. private sector should international competition become a reality.

The United States could obtain valuable technical and financial assistance if it expanded its cooperative MPS efforts. **In theory, international cooperation should be encouraged in basic scientific investigations or in areas in which the United States can benefit from foreign research (e.g., basic biomedical research and research in solidification) and discouraged in areas that might have near-term commercial applications or in which the United States holds a clear technological lead (e.g., continuous-flow electrophoresi$ and containerless processin~.** The distinction between these areas are, in practice, difficult to make and must depend on the unique characteristics of individual projects.

Competition in MPS

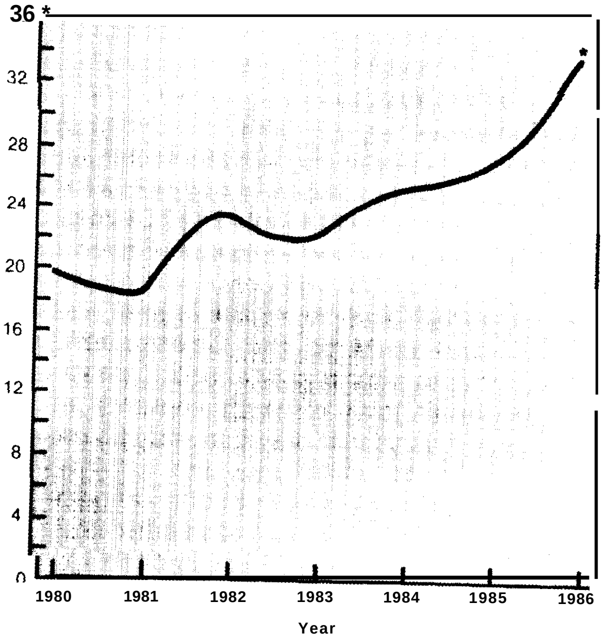
In most terrestrial markets the U.S. Government has tried to foster an international environment congenial to the open competition of enterprises. The preeminent role of governments in development of space technology, and the political and military sensitivity of much of this technology, have made it difficult to adopt similar policies toward commercial space activities. Given the cost and the complexity of doing research in space, it is unlikely that the private sector could pursue commercial MPS activities without some support from the Government. This assured role of Government makes it difficult to argue for free and open competition among commercial concerns. The question then becomes, what should be the nature and scope of Government intervention in future MPS markets?

Strategies for competition can focus either on increased support for U.S. industries or on the creation of barriers to foreign firms wishing to conduct microgravity research or sell space products. Support for U.S. industry can be increased either through a greater commitment to basic research or through direct support of industries or specific companies. A commitment to basic research would involve actions such as:

- **Increase funding for NASA research: Historically, NASA'S MPS budget** has been modest when compared to other NASA science and application programs. The proposed 1986 budget reflects a significant increase (fig. 8-1 1).
- **Encourage university and industrial support by established "research centers":** The House Committee on Science and Technology in its report on the 1984 NASA authorization bill recommended an increase of $5 million to be used "in part to establish at a university a center for basic research in the separation and purification of organics. "[43]

41 House Committee on Science and Technology, *Authorizing Appropriations to the National Aeronautics and Space Administration for Fiscal Year 1984,* H.R. Report No. 98-65, 98th Cong., 1st sess., 1983,

Figure 8-11 .—NASA MPS Funding Trends (millions of dollars)



"Budget request,

Such a center could provide a focal point for research in biological separation presently being conducted by NASA, various universities, and the private sector. A similar center was successfully established by NASA at MIT to conduct research in materials and has received substantial private sector support. As other areas of microgravity research show promise, these too could be supported by research centers.

- **Develop and encourage use of in-space research facilities: Such facilities** would include Spacelab and carriers for short-term research, and free-flyers and eventually a space station for long-duration and commercial operations.

Increasing research activities would generate basic knowledge about microgravity, thereby creating an environment conducive to commercial exploitation. It is also possible to support directly industries or specific companies in their efforts to find commercial applications for microgravity. A decision to do this might entail:

- **Expansion of current Joint Endeavor Agreement program: NASA's** JEA program is a partnership between industries interested in MPS and the Government. Current JEAs are conducted as "no exchange of funds" agreements whereby the private sector participants must pay for their own research and hardware development. The JEA might be expanded to allow for partial Government funding of such ventures.
- **Encourage firms to engage in joint research ventures in MPS:** The Government may choose to alter regulations or change laws to permit joint research ventures among firms in ways that may currently be prohibited. In the alternative, the Government could encourage the formation of organizations such as the Semiconductor Research Cooperative to do research into the application of microgravity science.
- **Financial support for private sector: Such support could include Government loans, Government-subsidized loans, or Government loan guarantees to companies attempting to produce and market new products.** These loans could be structured so that they were paid back if the enterprise was successful and forgiven if it failed.
- **Tax incentives: Tax credits** could be given for capital expenditures made in space manufacturing, similar to how they have been used in the past for solar energy work. In the alternative, income derived from the sale of space products could be made tax-exempt for a number of years.
- **Provide guaranteed Government markets: By** providing a guaranteed market for MPS products and equipment, the only risks remaining to the supplier are those involving development and production. This could be an interim step between a traditional contract arrangement with NASA and complete commercialization.

An alternative or parallel strategy for supporting U.S. commercial activities is one which emphasizes the creation of barriers to foreign competition in MPS equipment, products, and services. Such a strategy might include such elements as:

- **Limiting access to Shuttle and Spacelab:** The United States has almost complete control over the price and availability of the facilities necessary to carry out MPS research. Although it may not be politically or scientifically desirable, it would be possible to bring foreign MPS activities to a virtual standstill by exercising this control.
- **Encouraging "buy American" practices:** NASA could require that all U.S. research in MPS be conducted with hardware developed in the United States. This would reduce demand for European-developed free-flyers such as the SPAS and EURECA. NASA could also bring strong pressure to bear on its JEA partners to make sure that they conducted their early commercial operations with U.S. hardware.
- **Offer subsidized or guaranteed loans to purchasers of U.S. products and hardware: Should products** such as new pharmaceutical result from current MPS research, the Government could encourage their sale in foreign markets by offering attractive finan-

cial arrangements—thereby assuring that U.S. firms will capture the largest market share. A similar policy could be implemented with regard to the sale of hardware such as free-flyers.

- **Establish trade barriers to protect infant industries: Should foreign hardware or product manufacturers prove** more successful than their U.S. counterparts, trade barriers could be established to slow their entry into U.S. markets.
- **Government entry as supplier: In the absence of adequate private sector interest, the Government could enter as supplier. This** would probably be done only under extreme circumstances, such as if the MPS product or hardware had a strong relationship to national security.

Although **it would be possible to implement such policies, there is, at present, little reason to do so. It is possible that such strategies might do serious damage to our relationship with our allies and might preclude other cooperative space activities. Too immediate a concern with competition would accomplish little in the way of protecting U.S. private interests and could do much to injure the international reputation of the United States.**

Cooperation

Most MPS research in the United States and in other countries seeks basic scientific knowledge. Given this common goal, the primary reasons for engaging in cooperative activities are to reduce duplicative activities, to share costs, to encourage the creative cross-fertilization of ideas and to generate goodwill between nations. In addition, such cooperation reinforces the philosophical goals of the 1958 NASA Act and in the 1967 Outer Space Treaty which sought to encourage cooperation and ensure that space was used "for the benefit of all mankind."

A decision to emphasize cooperation in MPS research could take several different forms:

- **NASA formal agreements: To date, formal cooperative activities in MPS** have been limited, but have covered a wide range of activities. Foreign researchers, acting on behalf of their own space agencies or as NASA principal investigators (PIs), have made use of U.S. facilities such as drop tubes and towers, airplanes flying parabolic trajectories, SPAR sounding rockets, and, most recently, the Space Shuttle. Formal agreements have also been used by NASA to obtain valuable MPS-related hardware such as the ESA-developed Spacelab, which allows "hands-on" access to material and life science experiments, and the Canadian remote manipulator which allows the Shuttle to deploy and retrieve MPS payloads.

  Opportunities for formal cooperation in future MPS activities are numerous.[44] As a result of their MPS activities, the European nations and Japan have developed, or are developing, hardware which could be useful to NASA research efforts. Particularly noteworthy are the Materials Science Double Rack and the Biorack developed for use on Spacelab,[45] and the SPAS and EURECA free-flyers. Japanese interest in MPS and, specifically, in space bioprocessing technology, may also present the United States with opportunities for joint development or shared use of hardware.

  Formal cooperative ventures, such as the International Microgravity Lab (discussed above), could be used to form international research teams to investigate specific MPS phenomena. Such teams might initially concentrate on use of the Spacelab. NASA could encourage greater participation in its research efforts by foreign PIs and encourage foreign space agencies to grant NASA scientists similar treatment.
- **Informal cooperation at the level of the national space agency:** Informal agency cooperation offers an administratively simple, low-cost and low-visibility method of encourag-

[44] The space station, **currently under study by NASA, offers significant opportunities for formal international cooperation. This subject is discussed in detail in the OTA report** *Civilian Space Stations and the U.S. Future in Space,* OTA-STI-241 **(Washington, DC: U.S. Government Printing Office, November 1984).**

[45] *Spacelab Mission 1 Experiment Descriptions,* P. D. Craven (ed.) **(Marshall Space Flight Center, AL: NASA, November 1981), NASA TM-82448.**

ing cooperation on shared scientific goals. For this reason, NASA has developed informal working arrangements with numerous foreign space agencies. In MPS, NASA has been receptive to informal consultations with the scientists and program managers of other space agencies and has generally facilitated the international flow of information.

Specifically, NASA has encouraged its MPS Science Working Groups to interact with their counterparts from other countries, to share their experience, and to help define program goals. This unstructured cross-fertilization of ideas has contributed substantially to the dissemination of knowledge essential to the success of MPS projects. Although Pls at NASA have exclusive access to data from their experiments for 1 year, after this time they are required to deposit the data, in a usable form, in the National Space Science Data Center. This information is then freely available to all interested parties.

A more focused method of encouraging international cooperation might entail greater use of the various Science Working Groups, or some other organization, to coordinate research activities. The Science Working Groups play primarily an informational role, but they could be encouraged to take a greater part in organizing specific project interactions, identifying useful hardware and coordinating joint projects. It is important that the group given this responsibility be familiar with the details of specific projects to ensure the relevance of cooperative activities.

- **Informal communication among scientists: A great deal of information is transferred by individual scientists as a result of their personal and professional relationships. There has been an active dialog** in the scientific community on MPS, and the subject has been explored in numerous technical and scientific papers. A decision to encourage informal international communication among scientists might involve such activities as sponsoring symposia and making available funds necessary for travel. [n addition, formal arrangements involving the coordination of Science Working Groups or guest investigator programs would have the indirect effect of increasing the informal interaction among scientists.
- **Cooperation in multinational fora:** The United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) has been the principal multinational forum for debate of space issues. Although there is some current dissatisfaction with the United Nations (see ch. 3) and its committees, U.S. participation in COPUOS has in the past been beneficial. Should the United States wish to avoid purely "international" space programs and their attendant political problems, the United Nations may still play an important role. For example, one of the seven proposals for multilateral cooperation presented by the United States at the UN ISPACE '82 Conference was an intergovernmental meeting of experts in the use and management of space technology. [46]

  On February 4, 1983, NASA and Columbia University cosponsored the first such meeting. About 100 representatives from 40 countries and international organizations attended and discussed technical space problems in an informal multilateral forum devoid of the usual U.N. political issues, The success of this first meeting indicates that it might be a useful tool for coordinating international activities with regard to specific technologies such as MPS.[47]

There is no simple formula for deciding the appropriate level of international cooperation to pursue in MPS research. A well-structured and resource-conscious MPS program will undoubtedly wish to engage in some cooperative activities. Although the extent of international cooperation must depend on the unique characteristics of individual projects, some effort should be made to place these individual decisions in a coherent policy framework. At minimum, such a policy should ensure that:

1. **The benefits of cooperation are in reasonable proportion to the costs.** The term "benefits"

[46]See: *UNISPACE '82: A Context for International Cooperation and Competition,* **op. cit.**
[47]Ibid., app. c.

should include tangible items such as monetary return or technical advances and intangibles such as national prestige and the value of maintaining stable international relationships. The potential "costs" may be a loss of domestic jobs, contracts for services and hardware, and a potential competitive advantage in world markets.

2. **There is no negative impact on similar private sector efforts.** If the private sector is to be encouraged to take a greater share of the financial and technical risk associated with MPS research and hardware development, international cooperative ventures must not compete with them commercially.
3. **The objectives and program responsibilities are clearly defined.** Formal MPS cooperative ventures should have well-defined technological goals and should deal in advance with sensitive questions of data retention, patent rights, and proprietary information. The technical, human, and financial resources of the participants should be examined to assure that the costs of the research can be lowered and effectively shared.