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REPORT BY THE

Comptroller General

OF THE UNITED STATES

U. S. Must Spend More To Maintain Lead In Space Technology

Space manufacturing offers the possibility of exploiting the unique environment of space to produce materials superior to those produced on Earth or believed impossible to produce on Earth. Whether space manufacturing becomes a reality depends on the results of future materials research and the propensity of government and industry, both here and abroad, to invest. Success will require eliminating some difficult institutional barriers and creating incentives.

Despite high expectations among U.S. scientists, only limited success can be expected in the next 20 years due to low funding and limited backing by the Administration and the Congress. This could let foreign competitors rapidly overcome any technological lead in materials science in space now enjoyed by the United States.

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JANUARY 31, 1980

COMPTROLLER GENERAL OF THE UNITED STATES
WASHINGTON, D.C. 20548

B-197413

The Honorable Adlai E. Stevenson
Chairman, Subcommittee on Science, Technology, and Space
Committee on Commerce, Science, and Transportation
United States Senate

SEN06265

Dear Mr. Chairman:

You requested that we assess the near term potential of manufac~~turing in~~ space. Near term, as we have applied it, means any time between now and about the year 2000. Space manufacturing would take advantage of the unique environment of space to produce materials or products which are either superior to those produced on Earth or are believed to be impossible to produce on Earth. The most prominent characteristic of the space environment is its constant near zero gravity. However, space manufacturing, with permanent manufacturing facilities in orbit, is not a near term concept. Rather, it is a long term prospect with a number of milestones to be achieved. The first milestone requires the completion of a wide range of materials science research to provide the necessary scientific knowledge about the influence of gravity on materials processes to determine whether space manufacturing will be economically feasible or desirable.

Despite high expectations among many scientists in the United States, we concluded that only limited success can be expected in the near term due to low funding and limited support by the Administration and the Congress, with the possible added result that our foreign competitors could rapidly overcome any technological lead in materials science in space now enjoyed by the United States.

Appendix I is a detailed discussion of the issues identified in this report and contains alternative actions which AGC00036 we believe should be considered. The National Aeronautics and Space Administration's (NASA's) materials processing in space program is the current Federal effort which could lead to space manufacturing. This materials science research is also fundamental to other space industrialization activities which are evolving and which require more basic scientific knowledge about space, its environment, its impact on human life, and its advantages over terrestrial conditions. In this report, materials procesing in space is referred to as materials science research in space.

The views expressed in this report represent, collectively, the perspectives of nearly 100 scientists, program managers, economists, industrialists, and government officials with whom we talked in this country and in Europe. We also performed an extensive literature search on the subject.

As you pointed out in your request, the areas of innovation, productivity, and our national competitiveness are of great interest and concern to many in this country. The role of the Federal Government is critical in each of these areas in (1) sponsoring research and development that holds promise for innovation by the private sector, (2) providing a conducive atmosphere in which the free enterprise system can operate effectively to exploit Government-developed technology, and (3) encouraging cooperation among industry, academia, and Government to increase the rate of innovation and productivity and to enhance our national competitiveness.

NASA's program in materials science research in space is but one small effort which exemplifies these issues. The new knowledge to be gained from this research, according to many scientists, could go far toward improving a wide range of materials now used on Earth. Whether space manufacturing will become a reality depends on the results of materials research yet to be done and the propensity of government and industry, both here and abroad, to invest. Success will require the elimination of some difficult institutional barriers and the creation of incentives.

First, American industry participation is needed in identifying and planning the research that ought to be done. But industry, due to perceived legal barriers and disincentives--for example, Government restrictions on the use of Government-held patents and on the exclusive rights to those patents--is generally not willing to become involved.

Second, NASA has already developed much technology that offers commercial potential. Its future programs, such as its materials science program, will develop much more. The marketing and transfer of this technology to the private sector for commercial exploitation will need to be emphasized within NASA and organizational changes will need to be made to accomplish this effectively.

Third, since current efforts in materials science research in space are in an early stage of basic research, with costs disproportionately higher than similar research on Earth, American industry is unwilling to risk high, long term investments. If we are to achieve success and remain internationally competitive, the Federal Government must be willing to commit and risk enough resources to (1) complete essential basic research, (2) fund a large share of developmental and demonstration research, and (3) plan and commit enough resources for whatever follow-on facilities and transport services may be needed to enable future private enterprise activities in space. Current funding levels virtually assure very slow progress.

Fourth, interest in developing space for economic purposes has grown to the point that it is now a truly international enterprise. However, the U.S.' conservative approach does not compare favorably to the specific long term plans of the 11 members of the European Space Agency, especially West Germany, nor to the plans of the Soviet Union and Japan. Maintaining a high degree of international cooperation, while fully recognizing that we are competing with these same countries both technologically and economically, is a delicate issue in international diplomacy.

TRANSFERRING MATERIALS PROCESSING TECHNOLOGY TO THE PRIVATE SECTOR

The broad issues of transferring Government-developed technology to the private sector, and industry's willingness to use it, surfaced as central issues needing attention by the Administration and the Congress.

The materials science program provides an excellent case study of the problems faced by NASA in transferring its technology for commercialization. On the one hand, NASA needs the support and participation of private enterprise in planning the research and in using the resulting technology. But NASA is not organized to effectively gain the support and participation needed. On the other hand, private enterprise unquestionably could use much NASA-developed technology, but is generally unwilling to get involved due to deep-seated fears of Government regulations and restrictions, such as on patents, exclusive rights, proprietary rights, conflict of interest, antitrust, liability, and others. Obviously, addressing one set of barriers without addressing the other would probably have little, if any, positive effect.

While we touch on some of these issues in this report, we believe that because they apply generally to all Federal research and development programs, these issues are beyond the scope of your request. However, in discussions with your office, we were encouraged to pursue this broader issue in greater detail and we plan to provide this information in a separate report.

FUNDING

It is clearly premature to predict the variety of products and processes from materials research in space or their economic potential. Thus, the program receives little visibility or support in the Congress or by the Administration, and correspondingly, low priority and funding by NASA. Similarly, private industry cannot be expected to risk high, long term investments at the present stage of research.

Yet, if preliminary assessments by the scientists are correct, the eventual economic and social impact from new scientific discovery could be enormous. To prove or disprove these assessments depends on Government's willingness to invest with no guarantee of success. Nor is it possible, at the present stage, to predict how large the Government's investment should be. At current and projected funding rates, however, progress toward new discovery will be slow.

NASA is currently pursuing two or three specific technologies for commercialization. Strategically, their early success is viewed as critical to demonstrating the economic viability of producing materials in space which either are better than those produced on Earth, or which cannot be produced on Earth. Success in these demonstrations is expected to facilitate future budget justifications, which, in turn, should quicken the pace of materials science research in general.

FOREIGN ACTIVITIES IN SPACE

There is concern in this country about the growing emphasis and commitments by other countries in materials science in space. This concern is not that other countries are ahead of us now, but that once the Space Shuttle and Spacelab are in operation, emphasis by other countries could lead to technological and economic advantages which may be difficult to overcome. Many industrialists and economists believe that being "first to market" with new products or processes is extremely important in gaining a large enough market share to remain competitive.

These concerns, though somewhat overreactive, are not without justification. The United States, through NASA, encouraged and assisted the European Space Agency (and its predecessor, the European Space Research Organization) by providing guidance and offering launch and space flight opportunities, at reduced cost for cooperative endeavors and at full reimbursement for strictly European missions. The Europeans, of course, are grateful for this and would like more of these opportunities in the future.

However, some Europeans, recognizing that U.S. capabilities in space are more advanced than their own and, therefore, as viewed by NASA, cannot logically be shared on a coequal basis, resent their role as "minor partner."

European nations' desire to overcome this minor partner image, their uncertainties as to whether the United States will continue to provide access to American systems and services, and their drive to achieve technological parity in some areas of space activities have all provided impetus to develop capabilities to perform, independently, a wide range of activities in space. Following are examples:

--Of the early Spacelab flights to carry materials science experiments, most of these experiments will be conducted by Europeans.

--Beyond the materials science experiments currently scheduled for flight, West Germany has already committed resources to perform a comprehensive set of materials science experiments--something the United States has not done.

--Fearing U.S. sounding rockets would not be available to Europeans, West Germany developed its own sophisticated and highly successful sounding rocket system for use in low gravity materials research. Its assessment was correct--the U.S. program is being terminated for budgetary reasons.

--West Germany purchased an entire Shuttle/Spacelab flight to assure continuity of its low gravity materials science and other space-related research.

--The Ariane, a heavy satellite launching system, was developed by the French to assure an independent launch capability in Europe. This system is now competing with the United States to provide future satellite launching services.

--The French also plan to build their own unmanned, fully automated space lab for further independence in future materials science space research at what they hope will be greatly reduced costs compared to research on the Shuttle/Spacelab.

The capabilities demonstrated aboard the U.S.S.R.'s Salyut 6, the only space laboratory in permanent orbit, Soviet efforts toward a reusable shuttle, and the large number of top scientists committed to materials science research, leave no doubt that major technological achievements can be anticipated by Communist bloc countries.

Japan has more recently planned to devote substantial resources to its space development policy--roughly $1 billion a year for the next 15 years. This policy commits resources to materials science research in space.

In summary, while the United States still appears to be preeminent in space, there is little doubt that its lead has diminished. While we observed no immediate threat to our technological lead in materials science, it is the level of commitment being made by other countries, compared to the conservative American approach, that in time portends the loss of our technological advantage and "first-to-market" lead time for economic advantage--not unlike, or perhaps a continuation of, the phenominal industrial and economic growth of Japan, West Germany, and other European nations after World War II.

Whether the United States is to maintain its world leadership role in materials science as well as other areas of space development, depends largely upon events of the next 15 to 20 years. The opportunity to be the world leader in space is still available if we choose to exercise this option.

This report has been reviewed and discussed at length with NASA officials. The full text of NASA's response is included as appendix II of this report.

We are making no specific recommendations in this report because (1) based on our observations, we believe NASA's materials science program is effectively managed, given current constraints and (2) the funding levels and policy for international relations are essentially outside NASA's purview. NASA's programs of transferring technology to the private sector and the private sector's willingness to seek and use this technology will be the subject of our forthcoming report.

We are deeply grateful to the many individuals in the United States and Europe whose contributions were essential to this study.

As arranged with your office, we are sending copies of this report to the Director of the Office of Management and Budget, the House Committee on Science and Technology, the House and Senate Committees on Appropriations, the House Committee on Government Operations, the Senate Committee on Governmental Affairs, the House Committee on Foreign Affairs, the

Senate Committee on Foreign Relations, and the White House Office of Science and Technology Policy. Copies will also be sent to other interested parties.

Sincerely yours,

Elmer B. Staats

Comptroller General
of the United States

Enclosure

THE NEAR TERM POTENTIAL OF MANUFACTURING IN SPACE

THE IMPORTANCE OF GOVERNMENT-SPONSORED RESEARCH

Technological innovation, according to economists, contributes significantly to a nation's productivity growth and economic well-being. As much as 50 percent of this Nation's productivity growth since World War II has been ascribed to technological innovation, because in creating new products and processes for the marketplace, such innovation provides jobs for workers, and better equipment and means to produce high quality goods and services more efficiently. This, in turn, increases incomes and raises the standard of living while checking inflation.

Technological innovation, however, is a long, risky, and very costly process. It begins with creation of an original idea and proceeds to research, to development of a prototype, to market research, to gearing up for production, and is completed with the final production, distribution, sales, and servicing of new products or processes. Each stage requires new and increasingly larger infusions of capital, with commensurate increases in risk.

The Federal Government's share of the innovation process usually ends either after the research stage or after the development stage (i.e., for products and processes innovated by the private sector using Government-developed technology). Nevertheless, the Government has played an important role in innovation. Many technologies from space research, for example, have spun off into commercial and social uses in the fields of medicine, transportation, public safety, industrial processes, pollution control, energy, and of course satellite communications. The Federal research and development budget for fiscal 1980 is over $30 billion, which is more than the total spent by the private sector for basic research.

Thus, the need for continued Government support of research and development is not challenged--nor is its positive impact on productivity, job creation, and overall economic well-being. We, instead, strongly support the Government's role in innovation.

SPACE MANUFACTURING

NASA's materials processing program, a prerequisite to space manufacturing, is an example of a federally supported research effort which we believe could utlimately benefit the economy through the application of new knowledge--first on Earth and eventually in space.

Space manufacturing itself is a concept in which the processing or fabricating of materials in space would take advantage of special properties achievable only as a result of the unique characteristics of space. The most prominent characteristic is constant near zero gravity or microgravity. Other important characteristics include direct solar heating and high vacuum capacity. In the United States, the concept infers that, for the most part, actual manufacturing in space would be done by private enterprise for profit.

If space manufacturing is to become a reality, much research and development is needed to identify a wide range of opportunities which are

--unique to space,

--economically viable, and

--sufficiently attractive to entice investments by entrepreneurs, industries, and nations.

Of more immediate importance, however, is that materials research in space is already filling an existing knowledge gap about the effects of gravity on various stages of materials processes on Earth. Therefore, research efforts need not be justified solely on the premise that manufacturing in space is the single ultimate goal. For example, an executive for a major farm machinery manufacturer said that materials science research in space is very promising--not to build tractor parts there, but "to fill in gaps in our knowledge in a very unusual way."

A major oil company executive provided this example. He said that a refinery was shut down for 3 days at the height of the gas shortage during the summer of 1979 because bolts made of the wrong material fell apart. The loss was worth $3 million. He added, "if we can learn more about alloy selection in designing synthetic fuel plants, then everyone benefits. Trace elements can wreck a refinery designed for 20 years in less than a year."

MATERIALS SCIENCE IN SPACE

The initial program objective in materials science research in space is to develop a wide range of scientific data about the effects of gravity on various stages of materials processing. This data would become the basis for identifying various applications to new or existing products or processes which could result in improving their commercial value. But this is an evolutionary process.

Scientific research, so far carried out by a small cadre of materials scientists, has demonstrated that the behavior of materials during some stages of processing in constant near zero gravity is totally different than on Earth. The implications from this research are that certain materials processed in space can be stronger, purer, and more uniform. Some mateerials can be produced in space that, so far, cannot be produced on Earth.

To attempt to name specific products expected from the materials research to date, however, clearly would be inappropriate.

At the present stage of research, we believe it is appropriate to describe only the differences in phenomena which occur during various processes involved in making, altering, separating, or mixing materials under the influence of Earth's gravitational forces, versus microgravity in space. A few examples follow:

--On Earth gas bubbles rise in a liquid because they are displaced by denser fluids. In space these bubbles remain in place until solidification occurs.

--On Earth in alloys with two or more elements, the denser metal sinks and the less dense metal floats. In space they remain evenly distributed in a mix, allowing composite materials to be made.

--Heat creates density differences in fluids. On Earth the combination of heat, gravity, and the different densities of heated fluids causes the fluids to flow in a random or unpredictable way. This reaction is referred to as thermally driven convection and when it occurs, constitutent elements of fluids cannot be efficiently separated or synthesized. In space thermally driven convection does not occur, thus facilitating both separation and synthesis processes.

--The degree of purity attained on Earth in processing certain materials is often reduced by contamination caused by the walls of the containers in which the materials are processed at high temperatures. Yet, on Earth it is not practical to process materials without a container. In the weightlessness of space, it may be both feasible and practical to process materials without a container.

--On Earth gravity causes heavier particles to separate and settle at the bottom of a solution. In space such particles remain in suspension.

The average observer in Government or industry is unable to readily relate these differences in phenomena to anything which is economically useful, practical, or profitable. Only when specific products or processes are identified is the observer able to draw such a relationship.

For example, some scientific articles refer to products and processes like the perfect ball bearing, growth of flawless diamonds, light weight foam steel, the mixture of incompatible materials such as steel and glass, high purity medicines and vaccines, and perfect crystals. The average observer recognizes that these results are difficult, if not impossible, to achieve on Earth.

Many scientists agree that such products and processes may be possible in a microgravity environment, but they unanimously point out that these differences are not well understood. Some go on to say that, even if they were understood and specific applications were identified, private sector innovation to bring new products and processes to the marketplace will depend on economic factors, such as the availability and cost of transportation, markets for unique products, the cost to produce the products, economies of scale, the availability of high risk venture capital, and the willingness of Government and industry to invest.

According to some materials scientists, enough of the right kinds of research could create a virtual knowledge explosion. The prospects of new discovery has captured the imagination and excitement of materials scientists throughout the industrial world, and have raised hopes of beneficial applications in metals and alloys, composite materials, glasses, semiconductors, biologicals, chemicals, and other items.

If these assessments are correct and the economics become favorable, the eventual national economic and social impact could be enormous. One major benefit expected in the near term is the ability of scientists to isolate and study complex phenomena in ways never possible before. At the very least, according to scientists, industrialists, and economists, this should improve earthbound products and processes.

PROBLEMS AFFECTING THE PROGRAM

A number of difficult problems must be overcome before the program has much chance of achieving its highest potential. The two biggest drawbacks are simply that (1) specific products or processes which will offer significant commercial benefits cannot be identified nor quantified based on research to date and (2) the cost of materials research in space is disproportionately higher than that done on Earth.

Lack of visibility and support

Without identifiable and large-scale benefits, the program lacks visibility as well as support and commitment from the Administration and the Congress. This translates into low funding levels, at least as projected for the next 5 years.

Similarly, private enterprise, the ultimate benefactor, needs to become involved but is not likely to invest significantly in space research ventures until it can identify returns, and then, only if those returns can be predicted to begin within 3 to 5 years following initial investments. Since the program has not yet identified specific products or processes, industry has little basis for calculating returns on investment.

Gaining widespread nonaerospace industry support and cooperation toward space-related goals will be difficult for other reasons:

--Most nonaerospace companies have not even heard about space research programs and certainly have not considered getting involved in them.

--Few nonaerospace companies readily relate space-related research to their current private enterprise operations.

--Most nonaerospace companies are unaware of NASA's mandate to provide new technology developments for industry's own use. Instead, there is skepticism that NASA's motives are self-serving and self-perpetuating.

--Many nonaerospace companies have never done business directly with Government, and want nothing to do with Government in their day-to-day operations because they perceive severe Government interference and regulation, especially in current procurement contracting.

--Many nonaerospace companies do not understand the widely used Government jargon and perceive a massive amount of red tape in dealings which many companies, especially small ones, can ill afford.

NASA has developed an arrangement, called "joint endeavors," in which NASA and private sector participants can share the cost and risks of joint ventures with no exchange of funds. NASA's aim is to offer as much legal freedom as possible to the private participant within existing statutes and regulations.

While it appears that many of the barriers for private enterprise are as much perceptual as real, and can be overcome through the joint endeavors approach, some uncertainties remain. NASA, appropriately, is moving very cautiously, and private sector interest so far is limited. There are only three prospective joint endeavors and only one has reached final negotiations.

Funding constraints

Space experiments are more expensive than similar experiments on the ground. This is simply due to the high cost of transportation, life support, safety, hardware, and the difficulty of providing support such as electricity. NASA expenditures have increased in the last several years in preparation for the Shuttle era of the 1980s. However, most of these increases have gone into the Shuttle while resources allocated to materials research is still minimal, as viewed by people both in and out of Government with whom we talked. The fiscal 1979 budget for materials science research was still only about $20 million with just nominal increases for fiscal 1980, or about one-half of one percent of the current NASA budget. These funds must support not only the research, both on the ground and in space, but also the development of research facilities (hardware) as well. (They do not support mission-related costs of integration, flight, and operation.)

The limited funding could have serious adverse effects on U.S. progress in materials science and on any potential competitive advantage. For example, according to NASA and others:

--A few early commercial applications, such as those being pursued in the joint endeavors, are likely to be discovered. While these are critically needed to demonstrate commercial potential, much basic research in materials science is yet to be funded in order to establish a broad scientific base for identifying a wide range of commercial applications. This research begins with extensive preparation, experimenting and testing on the ground, as well as designing, developing, and testing related facilities which will house the experiments in space.

--A unanimous consensus was that most research must be funded by the Federal Government or it may not be funded at all. Due to the high risk, high cost, and lengthy payback periods, private industry cannot be expected to commit significant resources now.

--Hardware needed for follow-on experiments planned to begin in 1984, require 2 to 5 years to develop, test, and integrate into the Spacelab. Development which should have begun in 1979 or earlier has been deferred and is likely to slow the pace of the materials research program by 1984 and beyond.

--Similarly, experiments which should have been funded already are being delayed. Only 14 U.S. experiments have been selected and funded, of which only 9 have been selected for flight, compared to 39 selected and funded by Europeans to be flown on the first Spacelab. The 14 U.S. experiments were selected in 1977. None were selected in 1978 or 1979 and none will be selected in 1980. According to NASA officials, many worthwhile experiments cannot be funded until later years, though NASA had planned to select 10 to 15 new experiments each year.

--New investigators cannot be brought into the U.S. program due to limited funding. This frustrates many scientists in and out of the Government at a time when they feel more of the country's top scientists are needed in the program.

--Other industrial nations, most notably West Germany, France, Japan, and the Soviet Union, have made substantial commitments to materials science in space. At the current level of U.S. funding, the probability of early discovery which could lead to economic benefits is on the side of other countries.

--Early flight opportunities for materials science experiments on Spacelab missions will be occupied predominantly by other nations' experiments. Because of low U.S. funding, no new U.S. experiments are being undertaken and no related hardware facilities are being developed. This will mean that for flights beginning in 1985, no U.S. experiments can be scheduled, but in the meantime, European countries and Japan are proceeding with their plans and will likely request Spacelab space for additional materials science experiments beginning in 1985.

--Continued low funding by the United States coupled with the higher emphasis and commitments by other countries, increases the need for specific international ground rules and agreements to provide U.S. accessibility to experimental results--an increasingly tenuous possibility as new discoveries with economic potential begin to surface and grow in number.

Thus, until specific products and processes are identified, adequate funding resources are committed, and legal barriers to private industry participation are removed, U.S. progress will be slow.

Most of the problems cited above are perceived by the scientific community, both here and abroad, as resulting from a lack of clearly defined national goals and the necessary national commitment to carry them out.

CONCERN OVER FOREIGN SPACE ACTIVITIES

Those researchers in industry, academia, and Government who are most optimistic about U.S. prospects of materials research in space are deeply concerned about the growing emphasis and commitment by other countries compared to this Nation's conservative outlook. The researchers' concern is not that other countries are ahead of us now. Rather, once the Space Shuttle and Spacelab are operational and used by our international competitors, their heavy emphasis and commitment could lead to technological and economic advantages which may be difficult to overcome--the issue of being "first to market" with new high technology products and processes.

These concerns, though somewhat overreactive, are not without justification. West Germany has taken the lead in developing and building the Spacelab to be flown in the Shuttle. It has also made a commitment for the completion of a comprehensive set of generic research--something the United States has not done. This research is being complemented by expanding national programs among European Space Agency members, particularly in low gravity materials science research.

In cooperation with Sweden, West Germany developed a highly successful sounding rocket system, TEXUS. This system has been used in low gravity materials research in preparation for more complex and sophisticated research on the Spacelab.

The Soviet Union, with the only permanent orbiting space laboratory, the Salyut 6, has done impressive materials research in space and its work continues. Other Communist bloc countries have access to Salyut 6 and, at least one, Poland, has conducted a number of materials science experiments in it. The capabilities demonstrated aboard the Soviets' Salyut 6, their efforts toward a reusable shuttle, and recent reports that they now have about 350 top materials scientists actively engaged in space-related materials research, leave no doubt that major technological achievements can be anticipated by Communist bloc countries.

In its space development policy, announced in March 1978, Japan would spend roughly $1 billion a year over a 15-year period if all of its programs are fully funded. Part of that commitment is in materials sciences. Little is known about specific interests, but past emphasis and progress in glasses, optics, and semiconductors could indicate the direction of much of Japan's materials science efforts in space. The country's first test project is currently being developed with intentions of flying experiments on Spacelab in early 1985.

France is active in materials research in space, having flown manned experiments aboard the Salyut 6. France is taking the lead in developing and building the Ariane, a nonrecoverable rocket system. France has also made plans to build its own unmanned, fully automated spacelab, the Minos. It would be launched on Ariane, be remotely rendezvoused, and docked to a power module.

Other European nations, who, along with West Germany and France comprise the 11-member European Space Agency, are actively engaged in ground-based materials research. These efforts are preparatory to experiments which will vie for flight space aboard the Spacelab. These other European nations are also building many experimentation facilities for use on the Spacelab.

The Western Europeans, however, are deeply concerned about their ability to keep pace in materials science and other areas of space development. With the exception of West Germany, other members of the European Space Agency and the agency itself appear to be suffering from a lack of funding. Moreover, the European Space Agency has internal conflicts, stemming largely from the difference in size, capabilities, and interests of the individual member nations, coupled with a charter which requires unanimous agreement on many of the agency's policies and programs.

NASA has done much to encourage European space efforts, including assisting the European Space Agency and its predecessor, the European Space Research Organization. NASA has provided guidance and cooperative launch and flight opportunities in return for European contributions to NASA programs. In addition, the United States has provided reimbursable launch services for missions undertaken by European countries in pursuit of their interests. The Europeans are grateful for this and would like to see these opportunities continued.

However, space activities are costly and NASA, in line with the Administration's policy, established price guidelines to recover full costs for reimbursable services provided. These services are fairly extensive compared to existing capabilities of the Europeans.

The Europeans, recognizing they are heavily dependent on the United States, feel they will be given opportunities to use American facilities and services only at the discretion of the United States. Many Europeans resent this dependency and "minor partner" role.

The uncertainty about future U.S. intentions puts pressure on the Europeans to become more independent. The German TEXUS program was spurred by fears that U.S. sounding rocket opportunities would not be sufficiently available to achieve Germany's microgravity research objectives. (They were right--our program will be terminated by September 1980 for budgetary reasons.) The Ariane, a heavy satellite launching rocket, was developed to assure an independent European launch capability. That system is now competing with the United States to provide future satellite launch services. The Germans have purchased an entire Shuttle/Spacelab mission to assure access. A large German firm has arranged to purchase a portion of Spacelab space on another mission.

European Space Agency members want better cooperation internally as well as with the United States. They look to the United States to provide leadership toward an international coordinated space effort, but are fearful of being relegated to a minor role.

From a U.S. perspective, cooperation with European Space Agency members can contribute to international objectives as well as provide the greatest scientific returns at the lowest global cost, particularly at our present low funding level in materials science. However, while maintaining and reinforcing international relations, we also must remember that we compete with these same countries, both technolgically and economically.

Thus, developing cooperative efforts, while remaining competitive on an international scale, is a difficult issue for the United States as well as for the Europeans. Both the United States and the Europeans want independent programs as well as cooperative ones.

Thus, while the United States still appears to be preeminent in space, there can be little doubt that its lead has diminished. Whether the United States is to maintain its world leadership role depends largely upon events of the next 15 to 20 years. Its position will be a manifestation of the commitments made now toward future economic and technological advantages.

SUMMARY

The world stands at the threshold of a new frontier in space. In most categories, the United States has been the undisputed world leader, sharing that title only in part with the Soviet Union. NASA must be credited with achieving its primary goal specified by the National Aeronautics and Space Act of 1958--attaining national prestige and technological leadership in space.

Now, NASA must give more attention to its secondary goal of developing new technology which has commercial market potential. Its materials science program in space is such an effort. If successful, new technological discoveries could improve national productivity growth and international competitiveness, and promote economic well-being.

One of the keys to U.S. success will be the willingness of private enterprise to:

--Assist NASA in identifying the most essential materials research needed.

--Identify areas from this research which offer market potential.

--Take relatively long term investment risks to exploit new technology.

However, developing technology for commercial exploitation presents a real enigma.

--NASA is not organized or staffed specifically to carry out effective technology transfer nor to gain industry participation in planning and conducting space research on a cooperative basis.

--Even if it were, U.S. laws and regulations on patents, proprietary rights, exclusive rights, and antitrust are viewed by private firms as incompatible with such a goal.

--Lack of specifically identifiable products or processes has relegated materials science efforts to a low priority and low funding status, with the contracondition that without adequate funds and priority status, identification of specific products and processes will be slow to evolve.

If the scientists are correct, there is much new knowledge to be gained from space research in materials science

which could produce ecomomic benefits--first on Earth and possibly in space.

Success depends somewhat upon how well NASA manages its programs and adjusts to its goal of developing technology for commercialization. Our observations indicate that NASA's materials science program is being managed effectively given current constraints.

The predominant variables deal with funds, removing legal barriers, and gaining the support and participation of private industry. NASA has little or no direct control over these.

The United States has an opportunity to enhance its world leadership position in space in materials science. However, the U.S.' conservative approach does not compare favorably to the specific long term plans of the 11 members of the European Space Agency, especially West Germany, nor to the plans of the Soviet Union and Japan. Maintaining a high degree of international cooperation, while fully recognizing that we are competing with these same countries both technologically and economically, is a delicate issue in international diplomacy.

ALTERNATIVES

It is evident the United States has reached a point where it must decide on the importance of retaining worldwide technological leadership in space--a goal stated in the National Aeronautics and Space Act of 1958. The United States must also decide whether the prospects of future economic returns from materials science research in space are worth the costs and risks with no guarantee of success.

In our view, the two issues are related, but are not the same. For example, continuation of current funding levels in materials science may slowly produce scientific knowledge to eventually result in desirable economic benefits. However, if other countries are committed to pursuing materials science research more rapidly than the United States, as they now appear to be, any technological advantage we may currently enjoy would soon fade.

On the other hand, if the United States decides to accelerate the rate of materials science research by increasing its funding, the United States should be able to retain its technological lead, and simultaneously gain a distinct time advantage by being first to exploit any resulting technologies--both on Earth and eventually in space. Even if there were no economic advantages, an unlikely prospect according to many scientists, economists, and industrialists, the United States would still retain its technological lead.

We did not attempt to determine how rapidly the current rate of research and funding would need to be increased to achieve maximum economic and technological advantage. However, the current delays in hardware development, the number of good U.S. experiments that cannot now be funded, the need to bring more of the Nation's top scientists into the program, and the solicitation of European experiments to fill available space in the Spacelab, all suggest that two to three times current funding could be effectively spent. Such an increase should at least maintain parity between the U.S. and European materials science programs as well as between those of the U.S. and Russia.

Regardless of whether the materials science research program is accelerated, a primary key to success in the United States is the participation of the private sector. Thus, much of the Federal Government's role during the next 15 to 20 years should be directed toward (1) improving private sector confidence in the commercially-oriented goals of NASA's materials research program and (2) increasing private sector participation.

The private sector looks to the Congress and the Administration to provide the policy and legal framework to encourage the necessary participation, such as:

--Liberal application of antitrust laws to permit pooling of private resources to overcome the high cost, high risk nature of space ventures in their early stages.

--Reduction or elimination of restrictions on patents, exclusivity, proprietary rights, liablity, and conflict of interest in return for participation commitments by private firms.

--Minimizing the costs to U.S. firms by charging no more than incremental costs of flights, and treating capital costs of such items as transportation systems, launch facilities, tracking and control systems as sunk costs. (Ironically, this arrangement is offered to cooperative international partners, but not to U.S. firms.)

Due to the extraordinarily high cost of the Shuttle/Spacelab and experimentation facilities, it may be necessary to charge U.S. firms only a fraction of the incremental cost of flights in order to gain their participation, at least in the early rounds. Such an approach could be justified on the basis that the primary goal is to develop a wide range of scientific data toward commercialization by private enterprise, and that achievement requires private sector participation.

In addition, while the efficacy of special tax incentives and Government-furnished capital resources was not addressed in this study, such incentives may be necessary. NASA officials believe these are the best solutions because they make private capital available effectively.

The Congress and the Administration should consider whether additional international rules and organizational arrangements are needed to enhance the cooperative space-related endeavors in materials science and other areas in order to achieve the greatest returns at the lowest global costs.

If our goal is to maintain world leadership in space, then we must be prepared to bear the high cost of developing a growing number of evolving areas. Moreover, we should be sensitive to the fact that such a policy could connote a dependency role for the Europeans. Care should be taken to assure our foreign partners that a U.S. policy of preeminece is one from which all nations can benefit.

On the other hand, future space development will require new generations of facilities, equipment, systems, services, and even new concepts. The cost of developing these could be beyond the means of any single nation. Therefore, the efficacy of laying the groundwork now for future cooperative international endeavors should be considered, particularly whether such endeavors should be undertaken on a coequal versus a dependency basis.

The intent of considering all the above areas is to enhance the confidence and participation of the private sector of the United States and to lay the groundwork for international cooperation. These, in turn, should lead to the early and orderly development of the space environment for economic purposes. Failure of such creative and extraordinary measures on the part of the U.S. Government could lead to the loss of U.S. preeminence in space, both technologically and economically.

NASA

National Aeronautics and
Space Administration

Washington, D.C.
20546

JAN ? 1 1980

Honorable Elmer B. Staats
Comptroller General of the
United States
U.S. General Accounting Office
Washington, DC 20548

Dear Mr. Staats:

Thank you for the opportunity to comment on the GAO draft report on the near-term potential of manufacturing in space (Code 910302).

As stated in the enclosure, we agree that GAO has raised important issues of technological maturity, innovation, and foreign relations. However, we feel that significant progress on all three fronts must await scientific and technological achievements.

A similar letter is being sent today to the Director, Office of Management and Budget.

Sincerely,

Robert F. Allnutt
Acting Associate Administrator
for External Relations

Enclosure

NASA Comments on GAO Draft Report

"Near Term Potential of Manufacturing in Space"

The GAO report on "Near Term Potential of Manufacturing in Space" properly identifies the important issues of technological maturity, innovation, and relations with foreign activities; however, some clarification of these issues from current NASA experience in Materials Processing in Space (MPS) should be useful to a more detailed understanding of them.

In assessing the technological maturity, the novelty and utility of studying and practicing materials processing in space are recognized by most professional and industrial concerns. The most important current task of the MPS program is to demonstrate this novelty in exemplary processing areas so that utilization can begin as soon as possible. However, this approach requires emphasis on the development and demonstration of sophisticated experimental methods and apparatus rather than simply the commercialization of the few things that may have early payoffs for individual companies. Since most of the uses of space by the private sector will be innovated from these new technologies, the processes and products will generally be new and therefore impossible to list at this time. An understanding of the use of space as a tool for creative and innovative materials processing is well underway in several major areas and results are being published in the open scientific literature. On the basis of these phenomena, industrial firms can judge the utility for their own purposes and participate in MPS accordingly, either to learn more about enhanced control of processes on earth or to develop unique capabilities in space.

Private sector involvement is a key ingredient in the innovation of new technology through transfer and diffusion into the marketplace. However, the necessary support and participation of private enterprise is not simply an organizational problem. Current activities include both joint endeavors with the private sector where no funds are exchanged, and joint government/industry sponsorship of programs in the university community. In joint endeavors, institutional issues such as patent and data rights, exclusivity, liability and others are being examined on a case study basis to provide experience through which understanding the incentives and protection is necessary for joint involvement. In jointly sponsored university programs, more independence and separate responsibility are encouraged in the academic world, currently at the new MIT Materials Processing Center, so that industrial interests can be effectively combined with MPS results with a minimum but effective commitment of separate resources. These interactive government/private sector programs are small and exploratory because NASA is focusing on the specific problems of MPS technology which must be generated and institutional constraints which will serve as disincentives to its successful innovation in the future.

While the successful commercial application of MPS technology requires domestic government/private sector involvement, relations between NASA and other national programs are clearly important in establishing a firm scientific basis, whether performed in a collaborative or a competitive mode. Interaction between NASA and ESA, as well as member nations, has been restricted to sharing of mission opportunities until the scientific constituencies and modes of operation become established. At such a time, assessments of cooperation will be conducted which optimize opportunities but protect projects with commercial interest. Scientific participation from other nations is possible now in the NASA/MPS program through cooperative arrangements (no exchange of funds) as specified in Announcements of Opportunity. A fundamental principle of NASA's cooperative projects is that each side has full and equal access to the results. So far, an Australian and a French experiment have been selected for flight under these cooperative arrangements. Other countries have not found it possible or desirable to participate in NASA's MPS program under these cooperative conditions. A substantial commitment of resources is necessary to support the scientific base in any country interested in MPS so that technology cooperation can be eventually possible. The NASA MPS program is prepared to participate in international cooperative activities within its statutory and resource limits.

In a larger sense, the Europeans have taken and are taking steps to develop their own capabilities for space science and application purposes including systems and orbital facilities for materials research and technology development. GAO suggests that European uncertainties as to whether the U.S. will continue to provide access to American systems and services is one factor that has provided impetus to develop independent European capabilities. In this context, it should be noted that the U.S. in October 1972 formally announced its policy to provide launch assistance to other countries and international organizations for satellite projects which are for peaceful purposes and consistent with obligations under relevant international arrangements. The U.S. policy provides assurance that foreign users desiring to use U.S. launch services on a reimbursable basis will be charged the same as comparable non-U.S. Government domestic users. Also, with respect to the priority and scheduling for launching foreign payloads, they will be dealt with on the same basis as U.S. launchings, with each launching treated in terms of its own requirements and as an individual case. Further, in recognization of their contributions of the Spacelab (European Space Agency) and the Remote Manipulator System (Canada), NASA will fly certain European and Canadian missions at a lower cost, equal to what will be charged for U.S. Government agencies' missions. Only experimental missions with no near-term commercial implications qualify for the lower flight costs; for these missions NASA obtains for U.S. Governmental purposes access to the results. In light of this, it may be valid to conclude that the real impetus behind an independent European space capability would be their drive to achieve technological parity in space, also noted by GAO. It may also be the Europeans' view that development of the Ariane launch vehicle will help to reduce the costs of use of space for European commercial purposes.

GAO notes that the continued low funding by the U.S. coupled with the higher emphasis and commitments by other countries increases the need for specific international ground rules and agreements to provide U.S. accessibility to experimental results gained by other countries. In considering this suggestion, we feel it would be useful to anticipate that a request for U.S. access for foreign experiments results will most likely be countered with reciprocal requests for foreign access to the results of U.S. experiments. It would also be appropriate to note current practices and policy. A fundamental principle of NASA's cooperative (no exchange of funds) projects is that each side has full and equal access to the results of a joint project.

However, in the case of foreign missions flown at the full reimbursable price, NASA will not acquire right to inventions, patents or proprietary data, except in certain instances in which the NASA Administrator has determined that the mission results may have a significant impact on the public health, safety or welfare. (In such cases, NASA may obtain assurances from the user that the results will be made available to the public on terms and conditions reasonable under the circumstances.)

Important issues of technological maturity, innovation, and foreign relations, raised by the GAO, have been discussed from the programmatic viewpoint to provide additional insights. We agree that these are the major issues for the MPS program and significant progress on all three fronts must await significant scientific and technological achievements as the program moves forward into the era of the Space Transportation System.

Approval: Anthony J. Calio
Anthony J. Calio
Associate Administrator for Space and Terrestrial Applications

(910302)

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