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SPACE STATION NEEDS, ATTRIBUTES, AND ARCHITECTURAL OPTIONS

Commercial Opportunities in Space

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

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PREFACE

The McDonnell Douglas Astronautics Company has been engaged in a study for the National Aeronautics and Space Administration to determine Space Station needs, attributes, and architecture. The study, which emphasized mission validation by potential users, and the benefits a Space Station would provide to its users, was divided into the following three tasks:

Task 1: Mission Requirements

Task 2: Mission Implementation Concepts

Task 3: Cost and Programmatics Analysis

In Task 1, missions and potential users were identified; the degree of interest on the part of potential users was ascertained, especially for commercial missions; benefits to users were quantified; and mission requirements were defined.

In Task 2, a range of system and architectural alternatives encompassing the needs of all missions identified in Task 1 were developed. Functions, resources, support, and transportation necessary to accomplish the missions were described.

Task 3 examined the programmatic options and the impact of alternative program strategies on cost, schedule and mission accommodation.

This report, which discusses commercial opportunities in space, was prepared for the National Aeronautics and Space Administration under contract NASw-3687 as part of the Task 1 activities.

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Section 1
INTRODUCTION AND SUMMARY

As defined in the 1982 Office of Technology Assessment publication, "Civilian Space Policy and Applications," a commercial activity is one undertaken for profit in the public marketplace, and the term "commercialization" implies the transfer of technology from a research and development and/or federally supported phase of activity to a for-profit phase, usually under private sector ownership and control.

This report briefly examines the roles of government and industry in the commercialization of space, describes a methodological approach for stimulating the interests of potential users, presents several illustrative examples of potential commercial developments, discusses the role of manned space systems in space commercialization, and describes some of the issues and opportunities that are likely to be encountered in the commercial exploitation of the unique characteristics of space.

The results of the study activity summarized in this report suggest that interest in space facilities can be found among a number of commercially oriented users. In order to develop and maintain the involvement of these potential users, however, space demonstrations will be required, and commercial growth or evolution will be highly dependent upon the results of the initial in situ experience. Manned facilities will be required, especially for the conceptual research and development phases and for maintenance and servicing operations during production or operational missions. An essential requirement for encouraging the growth of commercial markets for space-developed products and services is that space facilities be easily accessible by dependable and regularly scheduled means.

The following organizations and individuals participated in the preparation of the material presented in this report.

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Section 2

THE ROLE OF GOVERNMENT AND INDUSTRY IN SPACE COMMERCIALIZATION

Corporate investment in development of a new product or service is generally undertaken only after a critical appraisal of the relevant technology, the anticipated development cost and anticipated return, and the market demand. The role of the government has traditionally been to serve as a stimulus to economic development by supporting research in high-risk pursuits with potential payback times longer than considered acceptable by private venture capitalists, or for technological developments having obvious social benefits to the populace as a whole.

In most areas of business opportunity, Federal R&D funds support or supplement much larger private R&D investment. With respect to space, however, the reverse has been true. The private sector has invested relatively little in space-related R&D for purposes of exploring new business possibilities.

Many reasons can be cited for the lack of private investment to date: Energy costs have been extremely high; the access to space is currently controlled by the government; and the markets for space industrialization are not yet developed. As the entry costs to users are reduced through the more effective utilization of time in space (i.e., the reduction in cost per hour of orbital time), and as access to space becomes a routinely predictable and scheduled event, the markets for products and services will develop. As the markets develop, flow of venture capital can be expected to increase, and a redistribution will occur in the relationship of Federal-to-private R&D investment in space.

The key to successful commercial operation is: (1) low-cost service; (2) stable, predictable, fixed-price policy; (3) success reliability; (4) schedule reliability; (5) predictable performance. These features will remove the

"Space Systems" risk from candidate commercial ventures. By taking the lead in stimulating progress in each of these areas of risk reduction, the government will significantly help industry in creating a viable and healthy economy based upon the commercial utilization of space.

The establishment of a significant commercial utilization of space systems largely depends on the orderly development of a reliable base of operations in space. The commercial missions will have to rely on the dependable support available from both manned and unmanned platforms. The basic STS program, including Spacelab, will provide an adequate beginning to support commercialization, especially in the areas of materials processing and remote sensing capabilities. As commercial development progresses, however, there will arise the need to expand and increase the support capability provided by the basic STS program.

Typical of the capabilities which will require augmentation are electrical power and energy and extended duration of the operational period of the mission. These needed expansions in basic capability can come about in several ways. One of the options is to transfer the support of the commercial payload from the Shuttle itself to a separate host free-flying spacecraft. This option could have certain advantages if the nature of the commercial work could be relegated to an automated, as contrasted with man-tended, mode of operation. Another attractive option is to increase the capability of the Shuttle by the addition of the Power Extension Package (PEP), a concept which offers the capability for extending mission duration, as well as supplemented power to potential users. Still another option, as the nature and interest in commercialization matures, is to support the missions from a manned space station which can support significantly expanded energy demands and mission durations and can provide on-orbit, man-tended operation and free-flyer servicing potential. Each of these options will indeed be pursued as mission needs dictate.

NASA must carefully study the spectrum of potential missions which could be performed in space, and design an initial capability which would satisfy the early demand. Any capacity beyond the initial level would be added as demand required, by those who have an incentive to satisfy that additional demand. NASA's interest then has been in identifying as many well-supported and documented missions as possible, and selecting the most attractive ones as drivers of the initial capabilities to be used as guides to program planning.

Mission requirements will include such things as electrical power, heat rejection, habitable volume, provisions for equipment, and the necessary level of logistics support. From these aggregated requirements, NASA can size the basic facilities needed and proceed to develop the technologies necessary to build these facilities.

As society views this process, NASA is seen as an enabling agency, charged with making the initial investment by developing the technologies for building the commercial facilities of the future. It is <u>not</u> necessarily seen as also having to make the investment in <u>building</u> these facilities. There is a growing perception that some or all of the cost of constructing facilities should be born by whatever entity stands to benefit the most from their use. Fortunately, there is potential for various institutions to profit from space commercialization by developing and practicing processes, making products, and rendering services yielding an attractive return and having great social value. There is thus ample opportunity for NASA to structure a program with an appropriate cost to the government and appropriate investments by those who would benefit the most from it.

While this opportunity presently exists, the means by which it can be accomplished has not yet been determined. What is needed is an approach or strategy for achieving or realizing an attractive return on an investment. An approach which will utilize the strengths of both NASA and the private sector in pursuing the commercialization of space is summarized in Section 3.

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Section 3
A METHODOLOGICAL APPROACH TO USER IDENTIFICATION AND DEVELOPMENT

Advanced space systems operating permanently in earth orbit offer significant new opportunities for the study of properties and the processing of materials, for production of new and unique products, and for providing unique services. By taking advantage of these opportunities and the beneficial attributes of space, promising concepts can be developed into commercial operations. By characterizing the concepts and their potential returns to industry, an impetus for the investment of private capital in mission development will be provided.

In order to define the space system capabilities which will be required in future years by commercial missions, it is necessary to identify actual commercial operations which are likely to occur in space. This further means that actual users must be identified. Missions in which these users are interested must be defined and subjected to detailed analyses of benefits, returns, and risks. This is necessary to provide a credible basis for user commitments, which are, in turn, required for facilities planning. Space system requirements must be based on the best information possible. Only committed users analyzing their own missions (in terms of real technical problems, real market assessments, and real costs, benefits, pricing, and so forth) can provide a legitimate basis for planning.

To achieve this end, the study team developed an approach to finding those real users and missions. The program described here is the result of that development. It produced committed users and their missions, which included the requirements imposed by the mission on the space systems it would use, and the characteristics and benefits of the mission necessary for further analysis. Criteria utilized in defining potential product areas or services included the following features: high market value; high value per pound; no practical alternative approaches; not labor intensive; and use of the unique features of space.

The methodology employed was intended to characterize users and to identify space system requirements based on authenticated (committed) users.

In the course of the study, we began to see a third objective which should be met. This objective was that sufficient understanding be gained from the user interaction to define the issues to be faced by NASA in order to encourage the commercial uses of space. As will be discussed below, the nature of commercial users and their concerns is such that any program developed without an understanding of those needs and concerns will most likely fail.

3.1 METHODOLOGY

The approach to user identification and development was based on the belief that a prime reason for the low level of commercial activity to date was a lack of understanding on the part of private companies and individuals of the opportunities offered in space. While most people have a reasonable grasp of the fact that microgravity and vacuum are present in space, few understand how these and other attributes of space might affect their particular technologies. Without this understanding, potential users were not likely to have recognized the benefits to be realized from carrying out their processes in space. Thus, the road to identifying new users had to begin with a means of communicating an understanding to private companies and individuals.

In order to generate this understanding, it is necessary to capture the user's interest. It was decided that examples of missions which were targeted to the user's technology would be presented, such that in the ensuing discussion, the relevant attributes of space and their affects on the technology would become clear. These "seed concepts" then would be the key to developing user understanding, and thus to any subsequent action which the user might take. Seed concepts have to be presented in an optimistic light in order to generate user enthusiasm.

A second factor in the process of developing user understanding, interest, and commitment was the issue of intellectual property rights. Because of the highly competitive nature of the high technology industries which would express interest, it was believed that such concerns had been inhibiting user activity and/or participation in space commercialization. If these firms could be approached in a manner which would ensure the protection of their major assets, i.e., concepts for new technologies, it would be much more likely to lead to specific areas of interest and activity.

With these premises, i.e., the use of seed concepts and protection of property rights, the methodological steps outlined in Figures 3-1 and 3-2 were followed.

The first step in developing the seed concepts which would be presented to the users was to define the attributes of space in functional terms.

Once the functional attributes of space had been identified, generic classes of missions could be derived from them. The types of missions which could be considered were limited, since they would be conducted in space and hence must be of high market value, high value per pound, low labor content, be unique and without alternative approaches, and use of one or more of the unique attributes of space. Consistent with the planned use of concepts derived from these attributes in presentations to new users, particular care was taken to describe the classes in the language of user technologies. For example,

FIGURE 3-1

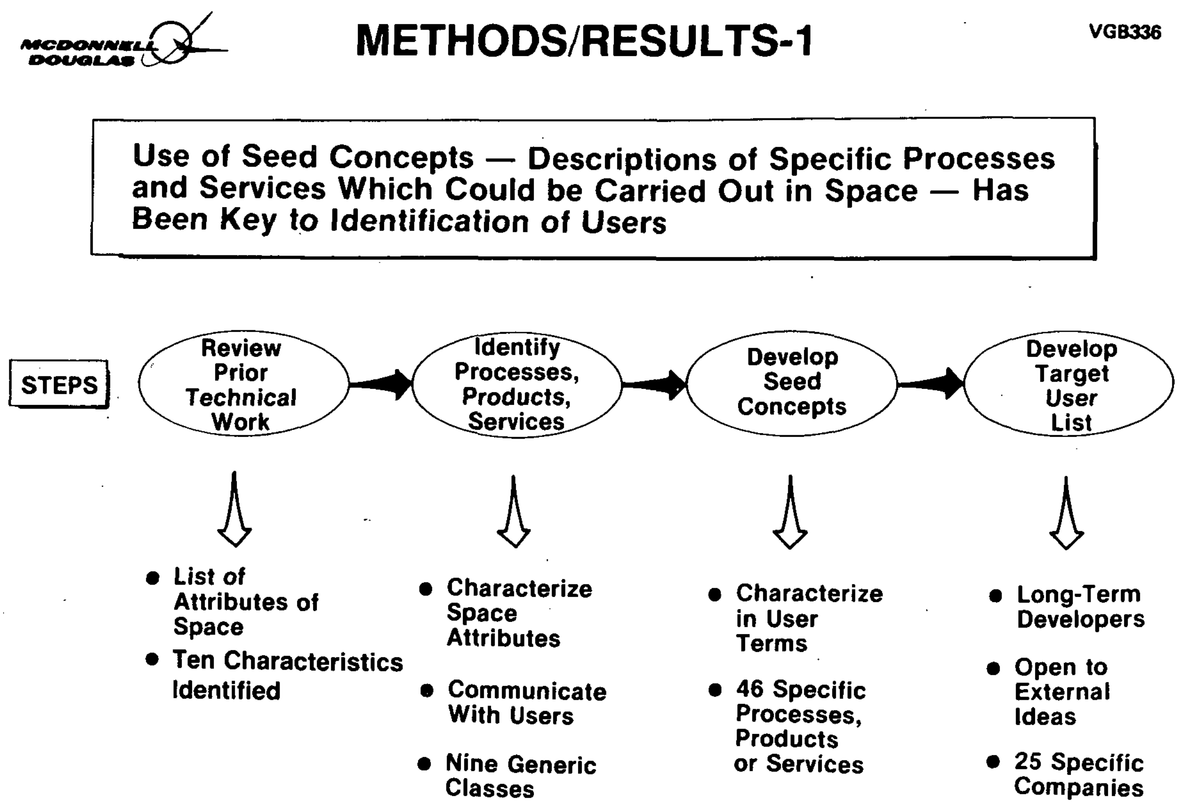
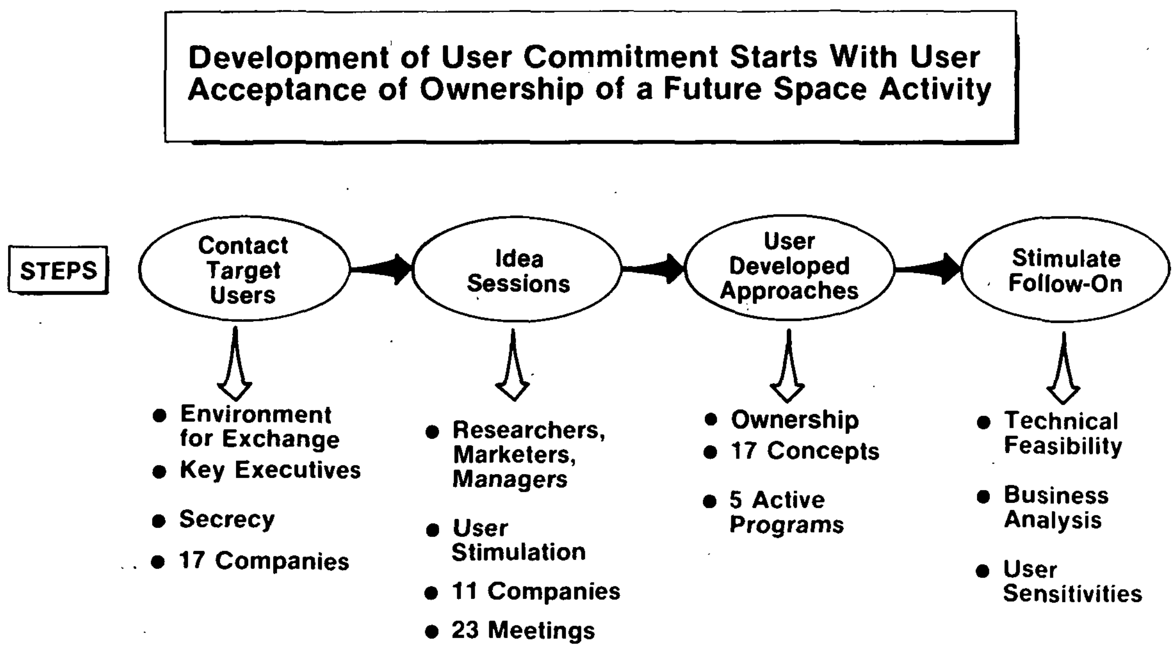


FIGURE 3-2

MCDONNELL DOUGLAS

METHODS/RESULTS-2

VGB337



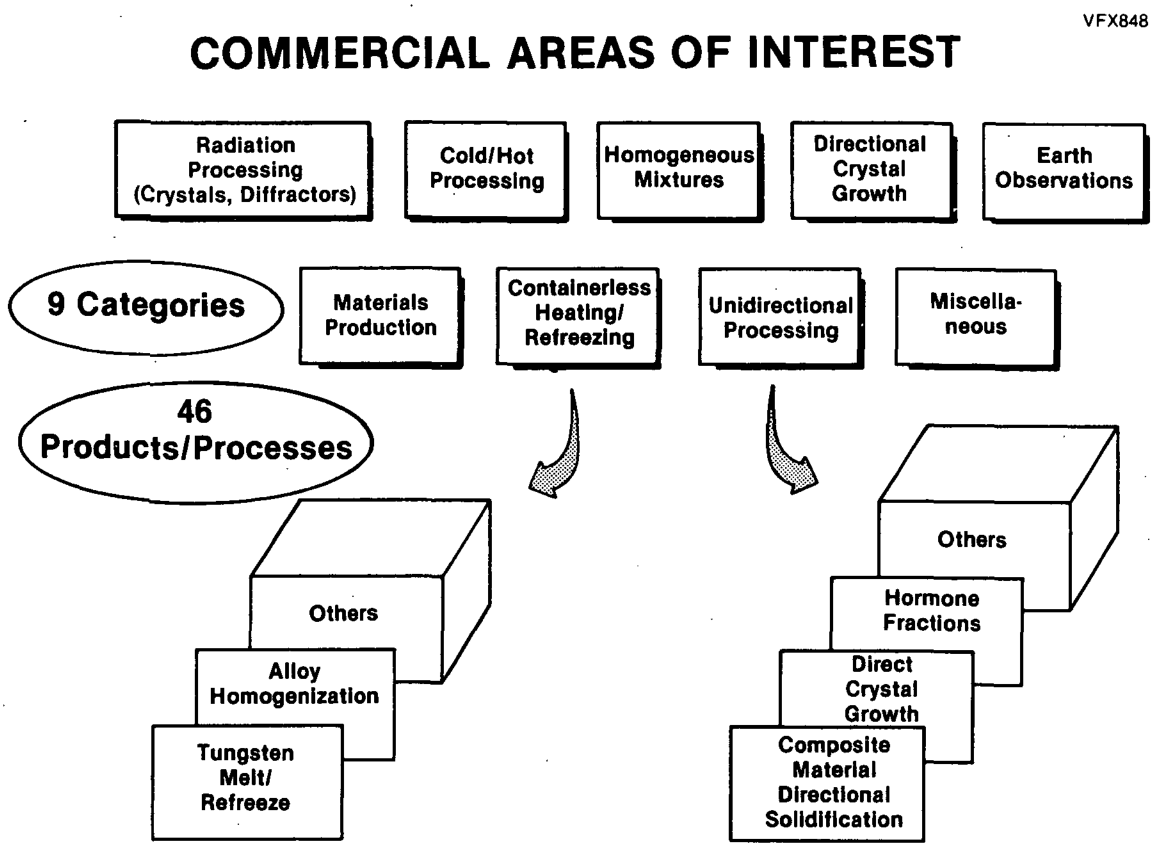
"vibration free" and "contamination free" were chosen because they represented solutions to user problems in ground-based processes.

The characterization of generic classes of missions permitted development of specific seed concepts which could be used to illustrate potential missions to new users. An interesting aspect of this step was that the same generic class of missions could contain seed concepts relevant to several industries. For example, the generic class "Unidirectional Processing" included seed concepts related to metal solidification, crystal growth, protein purification, and cellular fractionation. (Figure 3-3)

The seed concepts were conceptualized by drawing heavily on the existing base of literature, augmented by knowledge of user technologies. Each seed concept was treated as a candidate mission.

FIGURE 3-3

COMMERCIAL AREAS OF INTEREST



Once the seed concepts had been developed, the next step was to identify the companies to be approached. Consistent with the intent to use the seed concepts to foster understanding among the users, the companies chosen were matched to the seed concepts using several criteria. These included:

- The nature of the use and materials involved.
- The nature of the user's business and a characterization of the associated industry.
- The markets served by the user, and
- The attitude of the user towards complex, long-term development programs, and his ability and inclination to invest.

Figure 3-4 illustrates the pairing of seed concepts and companies which resulted from this process. One of the members of the study team, Booz, Allen and Hamilton, had an existing client base, which includes over 400 of the Fortune 500 as clients in the past five years. This provided an excellent resource from which to choose target companies. All of the industries of

FIGURE 3-4

46 CANDIDATE PRODUCTS/PROCESSES AND POTENTIAL USERS

VFX849

Miscellaneous

Containerless Heating/Refreezing

Materials Production

Earth Observations

Directional Crystal Growth

Homogeneous Mixtures

Cold/Hot Processing

Radiation Processing

Unidirectional Processing

Category	Product/Process	File Reference	Potential Users	Remarks
UNIDIRECTIONAL PROCESSING	COMPOSITE MATERIAL DIRECTIONAL SOLIDIFICATION	A-MP-017		ABSENCE OF OXYGEN, DUST, OPERATION IN VACUUM
	DIRECTED CRYSTAL GROWTH AS IN SILICONS	B-005	MONSANTO	
	DIRECTED QUARTZ CRYSTAL GROWTH	B-032	U.S. TIME	
	OTHER CRYSTAL GROWTH	B-033		GLASS FIBERS ARE THE SIGNIFICANT TARGET
	ORIENTATION IN HETEROGENEOUS COMPOSITES	B-034	BELL LABS	
	PROTEIN PURIFICATION AS IN IMMUNOGLOBULINS	B-036	MONSANTO SCHERING PLOUGH	
	CELLULAR OR PROTEIN FRACTIONATION	B-035	HYLAND	
	OTHER HORMONE FRACTIONS	B-019	ELI LILLY	

interest were well represented, and thus it was a simple matter to pick companies which met the criteria and to which they (Booz,Allen) had access. Where there was more than one potential contact in a particular industry, it was decided to contact each of them, but in sequence, starting with the one that was expected to be the most receptive. This was done in order to preserve the possibility that the first contact might want to adopt some of the seed concepts on a proprietary basis, and thus permit the deletion of any concept so selected from presentations to competitors.

Because of the importance of the interface with the user, four major guidelines for the user contacts were established:

- Firstly, the approach had to be made near the top of the organization. This was a key to meeting the verification requirement, since only at the top level can companies make expressions of interest or commitment that can be viewed as legitimate or binding.

- The second guideline required contact to be at the decision making level within the company at which investment opportunities are routinely evaluated and budgetary decisions made. While this guideline might be met by the contact required by the first guideline, the difference in rationale makes the additional guideline necessary.

- Thirdly, it must be recognized from the outset that the user contact and interaction process is not a one-time event. Multiple contacts with each user will be necessary if interest is expressed, and a long-term relationship will be necessary if that interest leads to a mission development program. Thus, the initial contacts (and subsequent meetings) must be approached in an open-ended manner, with an eye towards future activities and commitments between the two parties. This has an effect on the selection of the individual contact, in that it should be someone who would be receptive to the continuous contact that would become necessary, as well as a reliable participant in the follow-on activities.

- Finally, it is essential that an appropriate environment for discussion be established with the user, either when the initial contact is made, or at the time of the first meeting. From prior work with many of the firms to be contacted, it was recognized that the issue of intellectual property rights was of great concern, and that meaningful discussions of the user's technologies could not take place unless proper conditions were established. Because of their prior client relationships and privileged communication protection policies, Booz, Allen in particular, was in a unique position to act as a buffer between the user on one side, and MDAC and NASA on the other. Depending on the degree of protection required, only certain information would be transmitted across the buffer.

There are four general levels of proprietary restrictions which may be encountered in this type of work. In the first and least restrictive of these levels, a neutral party such as Booz, Allen is exposed to some of the details of the user's concept which if revealed would enable a competitor to duplicate the approach. While the understanding of this type of detail is necessary to effectively gather information, it does not have to be revealed in order to either obtain the information or discuss the mission with NASA or other companies. At this level of restriction, both the name of the company and a general description of its mission would be revealed. (The MDAC/Johnson and Johnson Joint Endeavor Agreement with NASA contains this type of restriction.)

At the next level of restriction, the company permits its name (and thus, to a certain degree, its industry or market) to be mentioned, but not the general description of the mission. Thus, unless the company is involved in but a few markets, the specific area with which the mission deals is not available to potential competitors.

The third level of restriction is one in which the company prefers not to be identified by name, but will permit either the general industry or a broad description of the mission to be revealed. This may occur when the company doesn't mind it being known that someone in a particular industry, market, or technology is working on a mission, but would prefer that they not be identified as yet. Thus, while a particular industry might be a logical one in which missions could be developed, competitors could not evaluate the threat to their markets as easily if the developer had been identified as either an industry leader or a new entrant.

The fourth and highest level of restriction is where neither the name of the company, the identity of the industry, nor any description of the mission is to be revealed. This situation can develop in an industry in which no indication has existed that any company is actively pursuing space-oriented missions or products. In this case, even the identification of the industry as one in which someone is now exploring a possible space application alerts the rest of the industry to someone's interest, and gives an otherwise unavailable edge to any interested competitors.

Once the companies had been identified, a specific contact was selected who satisfied the first two guidelines and was close to the area of interest. These contacts were typically at the level of President, Vice President, Executive Vice President, or Vice President of Research and Development. The reason for the contact was explained, and the contact either expressed interest himself, or referred to someone more appropriate. In either case, if interest was expressed, a meeting was then arranged at which the selected seed concepts were presented and open discussions held with the company representatives in any areas that turned out to be of interest.

Also during this initial contact, the subject of proprietary information was discussed. If the company felt it necessary, a confidentiality agreement was signed prior to the meeting. In other cases it was agreed that if proprietary information was exposed in the meeting, an agreement would be developed to provide for its protection. (There was one interesting instance in which no proprietary discussions were anticipated, but at the end of the meeting the users decided that they would like to retain the rights to some of the concepts discussed. Booz, Allen's representative who was conducting the interview than had to contact his corporate counsel to review a draft agreement, which had to be signed before he could be permitted to leave.) One of the agreements between Booz, Allen and a user (whose identity has been removed) is included in Appendix 1.0.

The approach to any proprietary questions was essentially that as described in Appendix 1.0. It was agreed to hold in confidence any proprietary information about the user's technology, and any mission concepts developed jointly or by the users themselves. If the users wished to adopt any of the seed concepts, those concepts would become the property of the user and be excluded from future presentations. This approach was well received by the users, and led to frank, open discussions which might not have been possible otherwise.

The meetings were usually attended by several people from the user's organization. Typically they represented both the management and research and development areas, while marketing and commercial development personnel were sometimes also present. Booz, Allen in particular used a common outline for their presentations, tailoring them to the audience by the selection of the seed concepts which were included. The general sections of the common outline were:

- A brief description of a generic space station system, including a manned space station, unmanned platforms, OTVs, TMS, shuttle support, commercial facilities, and so forth.

- An overview of the SSNAAO studies and their objectives, as well as an identification of the members of the MDAC/Booz, Allen team.

- A list of the attributes of space, highlighting the more functionally oriented ones.

- The specific seed concepts which had been selected for presentation to that user.

- A list of the issues to be addressed

- An outline of the next steps which might be necessary or desired

After the presentation, there was usually discussion of how the various attributes identified might affect the user's technologies, and general questions concerning the constraints on operations performed in space.

The most common result of the user meetings (and, fortunately, the most desirable) was the development of new concepts by the users. Because of their more intimate knowledge of their own technologies, users were much more able to assess the impact of space attributes, and, thus, to conceive of probable missions. Since they had developed the ideas themselves, they also felt a strong sense of ownership of those ideas. If users are to be persuaded to undertake a development program for a new mission, this sense of ownership is extremely important.

The seed concepts, then, function mainly as examples, serving to illustrate a point in terms of a user's technology and foster understanding. While some of them may eventually be adopted by an interested user, they will have more than fulfilled their purpose by having stimulated new user-developed concepts.

In some cases, the user's concepts were not generated until the second or third meeting.

If the user contact and meetings have been successful, the user-developed concepts represent not the conclusion of a process, but the beginning of a long-term requirement for support and assistance. In the short term, further meetings may be necessary to help the user to further develop the concept. Or, specific information might be required to support the users initial analysis of the technical merits of the mission. Also, the concepts and information to be covered by any confidentiality arrangements had to be agreed to.

In the longer term, there are many user needs that must be provided for by some form of an intermediary. First, the buffer between the user and the outside world, including NASA, MDAC, competitors, the press, and so forth, must be maintained, or the user will lose that avenue of communication and expertise. Second, only a disinterested third party can provide the means for an equitable agreement between NASA and the user, by protecting the user's data while conveying a knowledgeable sense of the user's needs to the Agency.

Third, an intermediary can also best represent the user's needs to the aerospace industry which will ultimately build the necessary facilities, while at the same time relating the specifics of the capabilities to be provided to the user in terms of the proprietary aspects of their mission. Finally, through its understanding of the commercial development process, an intermediary can assist the user in the necessary market, competitive, technical, investment, and regulatory analyses that must be performed. Unless these requirements for the continued development of the mission by the user are provided for in some way, that development will be impeded and stand to be terminated. Since this is not in the interest of either NASA, the user, or the country as a whole, some means of providing for these needs must be found if commercial use of space is to develop in this country before it does in others.

3.2 FINDINGS - RESULTS AND DISCUSSION

Application of the methodology as described proved to be successful in characterizing and identifying authentic new users. The results of this method as applied specifically by Booz-Allen included:

- Description of nine attributes of space
- Identification of nine generic classes of missions
- Development of 46 seed concepts
- Characterization of 25 target companies
- Contacts with 17 target organizations
- 25 meetings with 11 of the target organizations

- Creation of 17 user-developed concepts (see Appendix 3.0)
- Five active mission development programs in progress with newly identified users.

Each step of the approach is discussed in the following paragraphs.

Nine attributes of space of interest to potential considered users were identified from prior studies. These were:

- Microgravity
- Vacuum
- Unlimited heating and cooling
- Viewing capability/perspective
- Lack of atmospheric attenuation
- Unlimited radiation
- Sterile environment
- Non-social environment
- Vibration-free environment

These attributes were then described in ways that fostered user understanding and conceptualization. This was done by describing generic classes of concepts.

The nine generic classes of missions which were identified included:

- Unidirectional processing.
- Radiation processing.
- Hot/cold processing.
- Homogeneous mixtures.
- Directed crystal growth.
- Earth observations.
- Materials production.
- Containerless heating.
- Miscellaneous.

The classes functioned as focal points for matching seed concepts to users, for generating new seed concepts, and for relating missions across the classes.

In all, 46 seed concepts were identified, either from prior studies, or through conceptualization. Examples of these seed concepts include:

- Zone refreezing of precious metals.
- Metal-fiber composites.
- Production of glasses with unique inclusions.
- Unique pore size films.
- Cellular or protein fractionation.

The seed concepts were important for several reasons. First, they provided the examples for generating understanding by the users. Thus, these can be seeds for users to generate new concepts. Second, they served as focal points for the development of additional concepts by the study team; notably these permitted an understanding of how several attributes could be used, and how several users might cooperate. Such cooperation among users and their technologies is referred to as merged technologies. Finally, they furnished the starting point for the user interaction.

Using the criteria presented in the methodology section, Booz, Allen identified 25 organizations who appeared to be good targets for the seed concepts:

- AT&T (Bell Labs)
- Allegheny International
- Johnson Matthey
- Union Carbide
- Baxter Travenol
- Eastman Kodak
- Hoffman LaRoche
- Chemical Mfgrs Association
- Schering Plough
- A Venture Capital Firm
- Smith Kline Beckman
- Allied Corporation
- Dupont
- Monsanto
- Celanese
- Fluor
- IBM
- Eli Lilly
- Calcitek
- Perkin Elmer
- EPA
- FDA
- U.S. Time
- DOD

Additional potential contacts were then identified by the other study team participants. Because of the short time available for this study, the list of target organizations was limited to those which best met the criteria of use and materials, industry, markets, and attitude. The need to verify the approach also dictated a small initial sample.

Another reason for concentrating on a small selected group was the premise that direct contact followed by personal interaction (as opposed to a questionnaire or survey) was necessary for success. It was believed that the key to stimulating new users lay in showing them, in a very focused manner, how they could benefit from the attributes of space. Without the use of tailored seed concepts and personal contact, the chances of success would be greatly diminished. The logic then was to employ an approach with a good chance of success with a small but promising group of users, rather than a shotgun approach with a larger, poorly selected group. In the end, it was believed that the user developed missions would be the most valuable, so the process was to be directed at those organizations which were most likely to produce new concepts, i.e., those that meet the stated criteria.

From the group of 25 organizations which were targeted by Booz,Allen, initial contacts were made with 17. These 17 contacts are listed in Appendix 3.0 As planned, these initial contacts were made at high levels in the organization, where budgetary and development issues are understood and commitments can be made. In the first contact, the general purpose of the study was presented, and if interest was expressed, a request was made for a face-to-face meeting. It was carefully pointed out in this discussion that the contents of the meeting would be proprietary to the users and that any seed or user-developed concepts which the user wished to retain would belong to them. Where desired, confidentiality agreements were either discussed or made prior to the meeting.

Twenty three meetings were held with 11 of the 17 users who were contacted. In most cases, the meetings included the individual who had been contacted, as well as several senior research and management personnel. The meetings opened with a presentation which outlined the basic features of the study and its objectives, and led into a section which discussed some of the properties of space. With this as background, the presentation then focused on several seed concepts which were thought to be of interest to the individuals present. This part of the presentation was prominently marked as being proprietary to the users to make the point that any concepts which the users produced or found attractive would be their property if they so desired.

In virtually all of the meetings, the seed concepts were readily understood. They provided a focal point for discussion of the various properties of space and how they related to the user's technologies. Once an understanding of the properties had been established, the users all began to develop concepts of their own, using their much more detailed knowledge of their technologies. In all cases to date, these user-developed concepts are what have emerged from the meetings as the basis for future discussion.

During the actual presentation and ensuing discussion, there were two key features that proved important. First, it became obvious from the nature of the discussion that nothing short of face-to-face interaction with the user could be successful at this point in the relationship. Without this interaction the understanding of what could be done in space would not have emerged. And this understanding was vital to the development of concepts by the user which occurred later.

The other feature which turned out to be key to the eventual success of the meeting was the manner in which responses were given to user-generated questions and ideas. The various limitations on what could be done in space (costs, logistics, attributes, and so forth), were never portrayed as hard and fast reasons for not doing something. Rather, a factually based, optimistic response to questions and ideas posed by the users was offered explaining the nature of the limitation, and suggesting ways that it might be overcome or worked around.

This approach to user questions was based on the belief that in the past, too much emphasis had been placed on the problems of working in space, and not enough on the benefits. When users had developed ideas in the past, they were faced with a host of problems, virtually a challenge to their concept. Lacking a detailed understanding of space technology or the attributes of space, few users were able to rise to that challenge. While not overcoming all the problems facing a mission, the positive, optimistic nature of the interaction with the users has contributed to the emergence of several new, committed users in a relatively short time.

As can be seen from the ratio of meetings to users (23/11), there were many cases where more than one meeting was necessary to produce results. Sometimes it was a matter of giving the users more time to think about what they had learned, while in others it meant bringing additional user personnel into the discussions. In some cases, user concepts were produced in the first meeting, and the user activities which resulted (initial feasibility assessments, and so forth) stimulated other ideas. Further meetings were then requested in order to sound out those new concepts.

The situation which resulted from these meetings was precisely the one desired. Users were stimulated to produce concepts in which they had a sense of ownership, and thus ones which they wished to pursue. They had a source of expertise in the area where they needed it -- space technology.

Another benefit of the meetings was the establishment of personal contacts in the user organizations. The resulting relationships opened lines of communication between interested users and the space program.

Seventeen user-developed concepts were produced. Of these, five represent active development programs in user organizations, while the other 12 will require additional efforts by an intermediary to generate further use activity.

The five concepts being actively pursued by user development programs include:

• Iridium crucibles	Johnson Matthey
• Fee-for-service laboratory	Venture capital firm
• Biological processing	Eli Lilly Co.
• High-performance catalysts	Cooperative effort (two companies)
• New biological product	Proprietary user

The other 12 concepts requiring further investigation include:

• Biologically active membranes	Proprietary user
• New Plastics	Celanese
• Bone replacement	Calcitek
• Metal reforming	Nitinol
• Hazardous waste management	Ad Hoc association
• Second high-performance catalyst	Proprietary user
• Three new metal-based products	Proprietary user
• Gallium arsenide crystals	Various aerospace companies
• Two new products based on molecular biology and genetic engineering	Proprietary users

In addition to the concepts which emerged from direct meetings with the users, others were identified by other means. In one case, a user had read an article about Booz, Allen's work in an industry journal, and called to request a meeting. That article, as well as several others, resulted from a press conference held by Booz, Allen in October. A second contact was made through an executive of one of the firms contacted by Booz, Allen but which had expressed no interest at that time. This executive, however, spoke of the approach to another firm, and put them in touch with Booz, Allen when they indicated an interest in space systems.

Both of these contacts illustrate the variety of ways in which new users can be identified if the proper intermediary and approach are applied to the task. Booz, Allen's broad access to private industry, both in the U.S. and around the world, opens numerous paths by which new users can enter the program and enlarge NASA's constituency. In the same way, these paths generate a greater understanding of the commercial user community on the part of NASA and the aerospace industry, and help to identify the needs of the users. By studying the sensitivities of the users, i.e., those requirements and supportive actions which will stimulate user activity, a more efficient user development program can be created. For example, users are much more comfortable if they can communicate in their own "language" about their technologies and concepts. Knowledge of the users and their technologies (and thus their language), and the face-to-face interaction from which to identify the proper terms for communicating with the users is essential in developing solid working relationships.

3.3 REQUIRED FOLLOW-UP ACTIONS

Figures 3-5 and 3-6 present 11 of the 17 mission concepts developed during this study. The actions which are being taken or should be taken to ensure their continued development beyond the termination of the current study are as follows:

• Iridium crucibles	BA&H preparing market analysis/Johnson Matthey performing technical studies
• Fee-for-service lab	BA&H conducting investment analysis for venture capital firm
• Biological processing	Eli Lilly pursuing basic R&D internally and with NASA
• High-performance catalysts	BA&H assisting two companies in studying technical feasibility
• New biological product	BA&H arranging ground experiment for proprietary user with separate BA&H client
• **Gallium arsenide crystals**	**Evaluation of economic feasibility is required.**
• Biologically active membranes	The two companies involved must be brought together to discuss the mission
• New plastics	Celanese must analyze technical feasibility
• Bone replacement	Meeting must be held with Calcitek
• Metal reforming	Meeting must be held with Nitionol Products, Inc.
• Hazardous waste monitoring	Further contact with association committees necessary to identify possible actions

Another product of this study, in addition to the identified missions and users, is the understanding of the user interaction process as portrayed in Figure 3-7. The process is not only complex but time consuming as well. The fact that constant support of one kind or another is required to keep users active and interested is partially a function of the current state of the space industry. Because there are so few users, and virtually no two in the same industry, the competitive forces which normally drive commercial activity are not yet effective. When more users are active and more results have been demonstrated,

FIGURE 3-5

FINDINGS-1

VGB342

Four Identified Opportunities Must be Pursued Further

MISSION OBJECTIVE	USER	STIMULANT	NEXT STEPS
• Iridium Crucibles	• Johnson Matthey Inc	• Market in Excess of $100 Million	• Economic/ Technical Studies
• Fee-for-Service Laboratory	• Venture Capital	• New Business in Excess of $100 Million	• Market/Business Analysis
• Biological Processing	• Eli Lilly Co	• High Value, Health Care	• Basic Investigations
• High-Performance Catalysts	• Venture Group	• Market in Excess of $100 Million	• Make Product Prototype

FIGURE 3-6

FINDINGS-2

VGB343

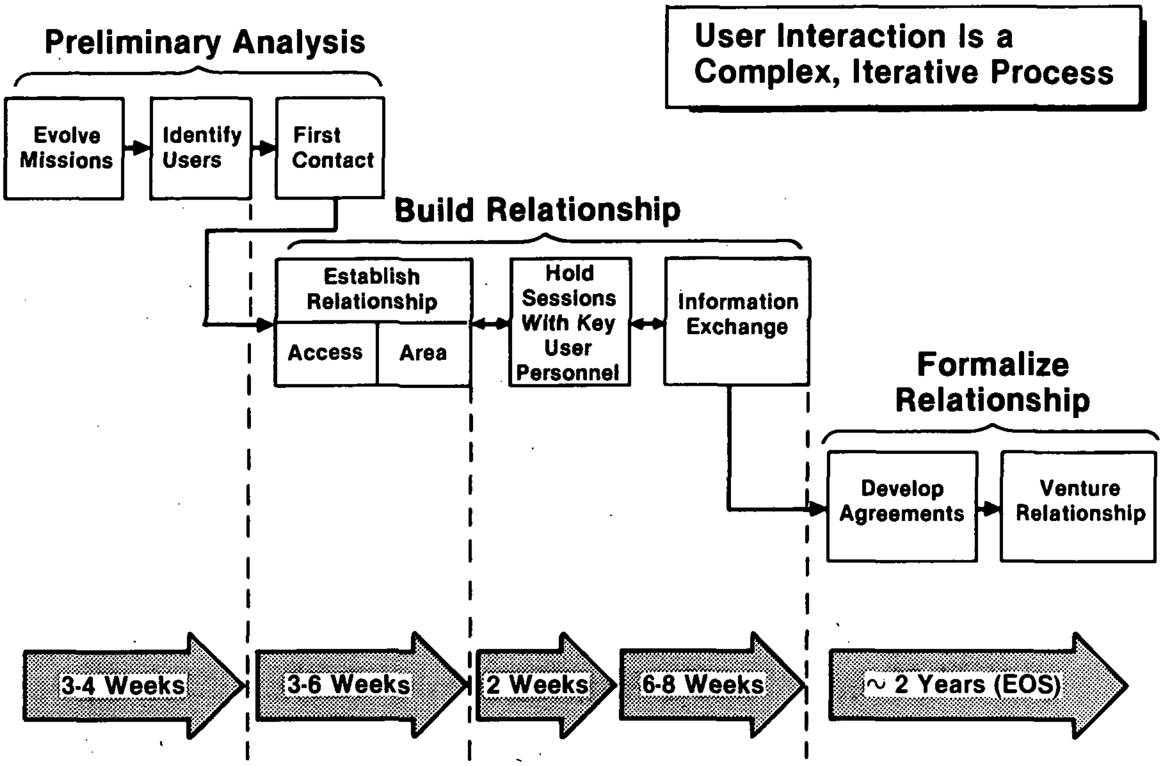
Significant Opportunities for Other Commercial Missions Require Further Investigation

MISSION OBJECTIVE	USER	MARKET
1. Gallium Arsenide Crystals	Multiple Companies	Lasers, Electronic Equipment
2. Biologically Active Membranes	Proprietary	Process Catalysis, Prosthetics
3. New Plastics	Celanese Corporation	To be Determined
4. New Biological Product	Proprietary	Unique Disease Treatment
5. Bone Replacement	Calcitek	Prosthetics
6. Metal Reforming	Nitinol	Reactor Linings
7. Hazardous Waste Management	Ad Hoc Association	Regulatory Requirements

FIGURE 3-7

VFX856

USER INTERACTION



less stimuli from NASA and Aerospace companies should be necessary. Until then, however, NASA must continue to encourage these potential users by whatever means possible if the commercialization of space is to proceed.

Figures 3-8, 3-9, 3-10, and 3-11 illustrate two cases from Booz, Allen's contact activity. Figures 3-8 and 3-10 present the steps taken to date in each case and Figures 3-9 and 3-11 outline possible follow-on activities. In both of these cases, a great deal of the follow-on work will involve coordinating the efforts of the user and NASA in support of the user's development plan. When this work includes the handling of proprietary data and an understanding of the user's operations, industry, markets, concerns, and constraints, the use of an intermediary becomes essential.

FIGURE 3-8

VGB338

CASE STUDY-1

The Iridium Crucible Mission is an Example of the Method and Results Obtained

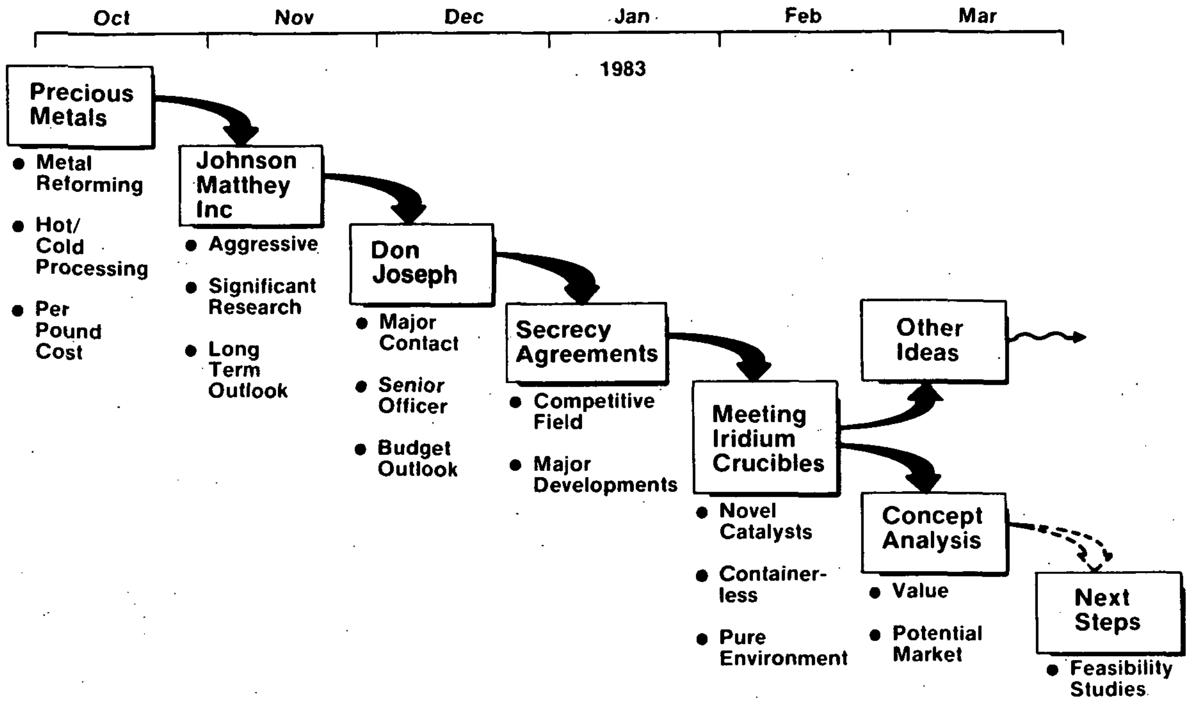


FIGURE 3-9

VGB339

CASE STUDY-2

The Phasing of the Development Plan Will be a Function of Coordinating NASA and User Needs

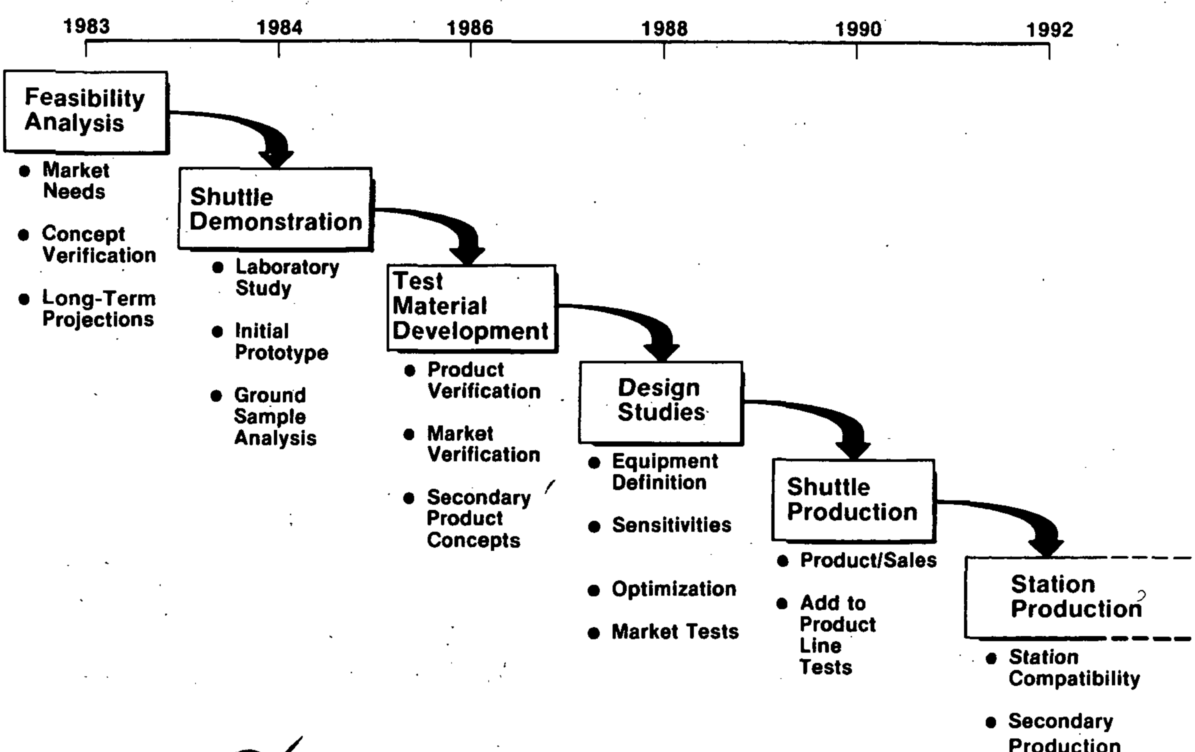


FIGURE 3-10

VGB340

A SECOND CASE STUDY-1

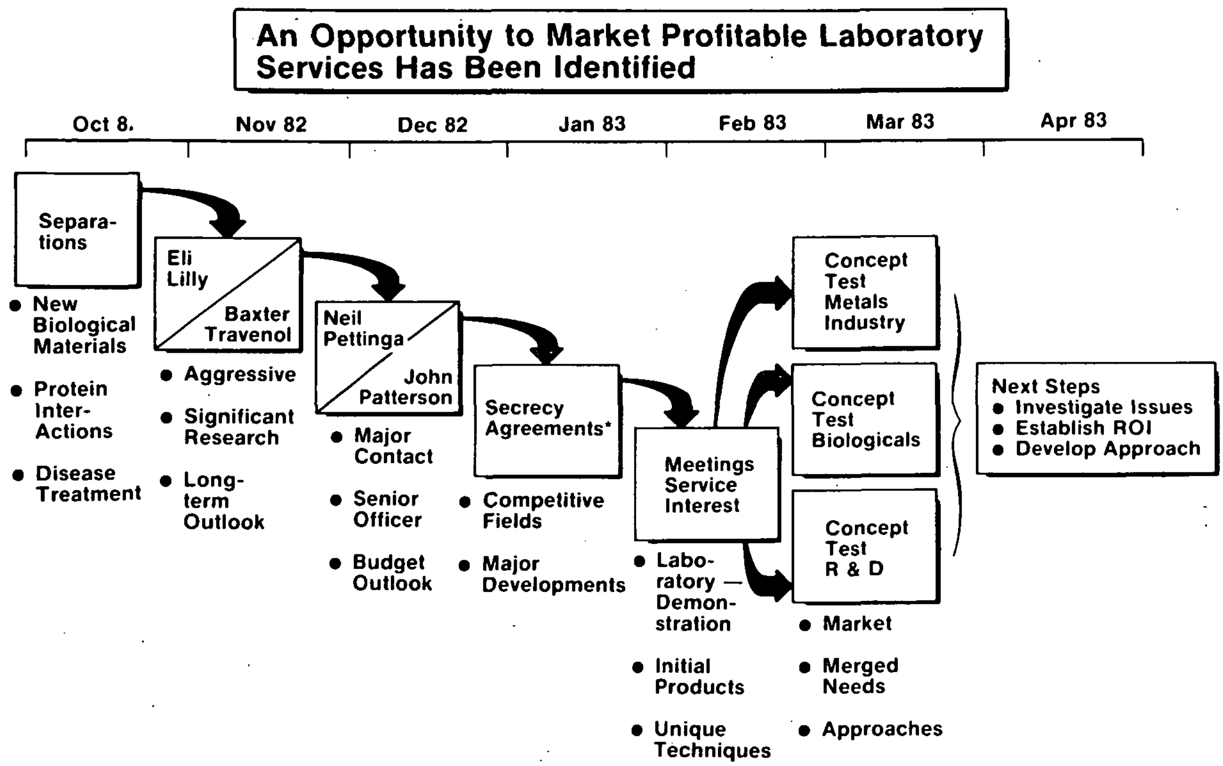


FIGURE 3-11

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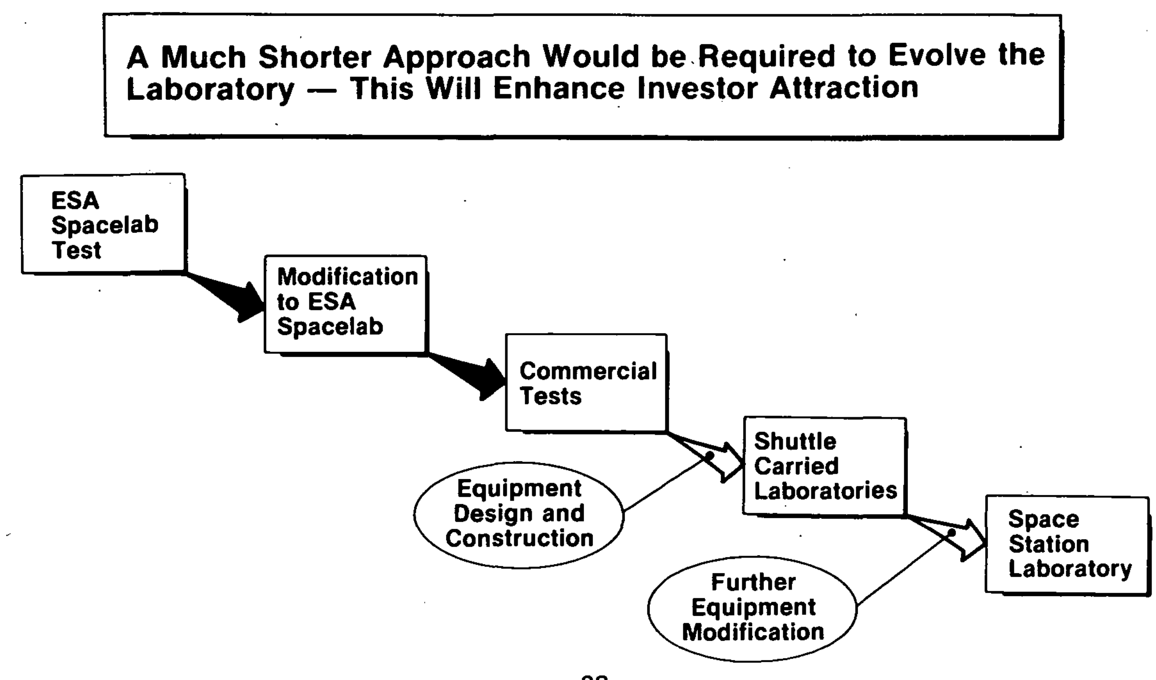
A SECOND CASE STUDY-2



3.4 LESSONS LEARNED

Figures 3-12, 3-13 and 3-14 summarize the three basic lessons learned from this study. First, user commitment and continued activity can only be ensured through the follow-on efforts of NASA, an intermediary, and the aerospace industry. Second, the success of the work to date establishes that further contacts will produce additional new users. And third, there are four key elements to any program designed to produce committed users of space:

- Buffered access
- Use of seed concepts
- Continuous stimulation
- NASA commitment.

Buffered access provides the assurance the user requires to participate without feeling compromised. Seed concepts are necessary to generate the understanding which will lead to new mission concepts produced by the user. Continuous stimulation is required to channel the NASA/aerospace industry knowledge of space technology to the user and encourage his interest. And demonstrations of NASA commitment (as in providing the services of an intermediary, defining exemplary exchange agreements for user support, and committing to the development of orbital facilities and capabilities) will assure the users of NASA's interest to their success.

FIGURE 3-12

MCDONNELL DOUGLAS

LESSONS LEARNED – 1

VGB344

Follow-On Efforts Will Be Required to Ensure User Commitment

- **Demonstration of Feasibility**
- **Prototypes for Business and Market Analysis**
- **Recycle User Ideas to Stimulate Others**
- **Identify Joint User Opportunities**

FIGURE 3-13

VGB345

LESSONS LEARNED-2

Further Contacts Will Produce New Users

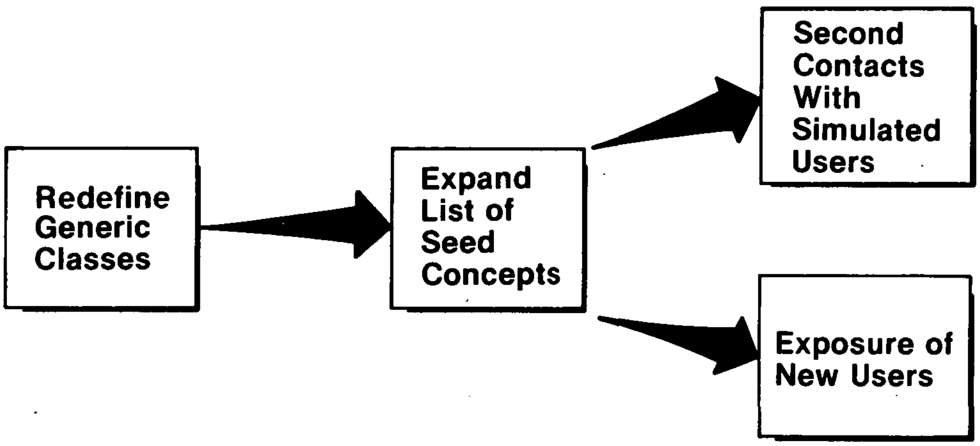


FIGURE 3-14

VGB346

LESSONS LEARNED –3

Four Elements Are Key to Identification of Committed Users Who Will Remain With the Program Throughout

- Buffered Access
- Seed Concepts
- Continuous Stimulation
- NASA Commitment

Figure 3-15 lists the four primary issues which surround any attempt at developing user interest in space. First, some provision must be made for the treatment of user proprietary information. Second, significant benefits can accrue to all sides if an intermediary function is properly defined. Without it, user development will continue to stagnate. Third, the needs of the users and of NASA are interdependent -- the users need information on what can be done in space, how to do it, and access to the means to do it, and NASA needs a constituency of active, interested users both to demonstrate the need for a space station and as a basis for designing it. Finally, the commercial user development process requires that progress be demonstrated early and often if the users are to continue their investment in mission development. This means that ample opportunity must be provided for users to test their missions, either on the ground or in space, which again demands close cooperation between the user and NASA, and, as necessary, an intermediary. This last point is also illustrated in Figure 3-9 where a number of tests and demonstrations, and analysis of the results, can be seen in the long-term development plan for iridium crucibles.

FIGURE 3-15

VGB347

MCDONNELL DOUGLAS

ISSUES

Four Topics Must be Addressed to Ensure a Continuous Commercial Development Program to Parallel Space Station Expansion

- **Intellectual Property Rights**
- **The Intermediary Role**
- **Interrelating NASA Needs and the Commercial Development Process**
- **Time-Phased Evidence of Success**

3.5 CONCLUSIONS

The development of commercial users of space will not occur without follow-up. Without follow-up, user development will stagnate until an aggressive user demonstrates outstanding success and competitive forces prevail. And if NASA-led user development fails, that success may well be foreign.

Two conclusions (Figure 3-16) can be reached about the continuing goals of a user development program: the need to identify additional new users, and the need for NASA to provide visible, active support. It has been established that new users can be identified. Others can be identified by continuing these efforts, and providing for demonstrations to support user efforts and encourage others to participate.

FIGURE 3-16

CONCLUSIONS

VGB348

Commercial Missions Can be a Significant Part of Station Activity — Needs Must be Addressed in Architectural Options

OBJECTIVES	RESULTS
■ Identify Committed Users	■ Interested Users Can and Have Been Identified ■ Demonstrations are Required to Maintain a Committed User
■ Ensure Continued Active Support	■ Manned Facilities Will be Required for These Demonstrations ■ Growth of User Group Will Follow Space Demonstrations

Manned facilities will be needed to support user demonstrations and production, and successful demonstrations will stimulate further interest (in the best competitive tradition). It falls to NASA to make the manned facilities available to the users (both via the shuttle and Spacelab, and later on a space station) and thus ensure the timely development of what will become a healthy and vigorous component of the U.S. economy.

If these conclusions are to be acted on, a compromise must be reached between the internal NASA goals for development of a space station and industry's need to develop, own, and operate the missions. On the basis of the results achieved in this study, it is believed that such a compromise can be achieved through the proper use of a disinterested third party.

A third party, operating as an intermediary between the private and government interests, can provide the support and assistance required to expand commercial space opportunities, and enable the government and the private sector to work with each other in the conceptualization and implementation of commercial missions. This third party has clearly defined roles which derive from the barriers to communication which exist between the government and private interests. If properly selected, the third party will:

- Serve as a buffer between the government and private interests, through which sufficient information can pass to satisfy both sides, while protecting private intellectual property rights and long-term investments.

- Understand the needs of both the government and commercial interests, and, by defining and characterizing the needs of each to the other, provide a negotiating platform through which appropriate agreements can be reached to assure each of a fair and equitable meeting of those needs.

- Understand the capabilities and interests of the aerospace industry to provide the time-phased space capabilities needed.

- Understand the long-term commercial development process, and, by providing the guidance necessary to balance the dissimilar forces which drive government and private interests, help the government bring about the commercialization of space in an efficient manner.

- Through its contacts in the commercial user community, provide access to the levels of user organizations at which there is an understanding of the opportunities and at which commitments to long-term development can be made.

In essence, the third party should provide buffered access to the proper levels of industry, and facilitate communications between the government and the private sector through its understanding of the commercial development process and the forces which drive both the government and private efforts. These requirements can be met through the use of a third party which:

- Provides a factually based, optimistic view of what can be done in space, thus fostering a better understanding of the potential offered by the attributes of space.

- Stimulates conceptualization of user-specific ideas, creating an incentive for the user to participate.

- Provides an intermediary for negotiation in issues of intellectual property rights, the proper vehicles for government/industry cooperation, and equitable social and economic returns for both sides.

- Provides avenues of communication among parties; not only between government and individual private interests, but also among various private groups which must interact to achieve desired ends.

- Portrays the time-phased commercial development process in such a manner as to be understood by both parties, so that each can plan the steps necessary for it to complete the program.

- Fosters commitment to process demonstrations, including on-orbit operation of prototypes.

These services, when provided by an appropriately chosen intermediary, can have a significant impact on the commercial development of space. If such efforts are continued, they can provide substantial support for the development of a space station and other space capabilities.

Section 4
EARLY OPPORTUNITIES FOR SPACE COMMERCIALIZATION

The commercial uses of space are predicated upon utilizing the unique characteristics of a space-based system, including spatial location, viewing opportunities, and the environment characteristics of space itself (zero gravity, vacuum, and lack of atmospheric attenuation) to service a potential market application.

Over the last two decades, many institutions--academic, industrial, and government--have investigated potential commercial applications of space-based systems. Of these many surveys, the most promising areas suggested to date include space manufacturing, communications, and remote sensing.

In the following pages, the forecast of the market demand and the role of manned space systems in meeting this demand will be reviewed for each of these three key areas.

4.1 SPACE MANUFACTURING

In the case of many of the concepts which have been advanced to date in the field of space manufacturing, neither the market economics <u>nor</u> the technological approaches have as yet been fully validated. In fact, of the many potential space manufacturing processes examined over the last two decades, only one has matured to the point of flight demonstration. This is the Electrophoresis Operations in Space (EOS) Program, which represents a Joint Endeavor Agreement between NASA and the McDonnell Douglas Astronautics Company and its teammate, the Ortho Division of Johnson and Johnson.

4.1.1 <u>Electrophoresis Operations in Space - A Model for Space Manufacturing</u>

Under a Joint Endeavor Agreement with NASA, MDAC is currently developing the technology to accomplish electrophoresis operations in space. The development plan involves process proof of principle, pharmaceutical product evaluation, and demonstration of a production prototype system. (MDAC has contracted with Johnson and Johnson to conduct the clinical trials, secure FDA certification, and market the product.) Still to be determined are the ultimate levels of resource use and the concept flexibility needed to support future needs, new products, etc.

The following analysis was developed to assist in future space planning by defining possible expansion of EOS as the nation's space program matures through routine Shuttle use and development of new space systems--manned and unmanned.

The initial market analysis conducted by MDAC prior to embarking on this program investigated products amenable to electrophoresis (hormones, enzymes, cells, and proteins), defined the benefits and needs of each, and sought to identify those products with a uniqueness that could make EOS a favorable method of production. These analyses led to the identification of 12 products that could offer significant social and economic benefits to the rest of the world (Figure 4.1-1).

FIGURE 4.1-1

CANDIDATE PHARMACEUTICAL PRODUCTS

12 TYPICAL

VGB325

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Typical Products	Beneficial Medical Application	Function/Status	Annual Patients (USA)
α_1 Antitrypsin	Emphysema	Research Quantities Only Now	100,000
Antihemophilic Factors VIII and IX	Hemophilia	100% Terminal by Age 40	20,000
Beta Cells	Diabetes	Possible Single-Dose Cure	600,000
Epidermal Growth Factors	Burns	Replacement Skin Grafting	150,000
Erythropoietin	Anemia	Replacement Transplants/ Transfusions	1,600,000
Immune Serum	Viral Infections	EOS Provides Higher Purity	185,000
Interferon	Viral Infections	Potential May Be Unlimited	$>$10,000,000
Granulocyte Stimulating Factor	Wounds	Research Quantities Only Now	2,000,000
Lymphocytes	Antibody Production	Replace Antibiotics/Chemotherapy	600,000
Pituitary Cells	Dwarfism	Currently Not Curable	850,000
Transfer Factor	Leprosy/Multiple Sclerosis	Potential for Other Applications	550,000
Urokinase	Blood Clots	Low Development Costs	1,000,000

The EOS products investigated exhibited varying degrees of demand. For example, while beta cells may offer a one-time cure for diabetes, many patients may continue to use insulin as a preventive if the cost of beta cells is prohibitive.

The EOS annual domestic market has been estimated to be in excess of $7 billion. This is based on usage by 75% of the patients for each product. This is probably a conservative (low) estimate. As an example, there are 800,000 emphysema sufferers in the United States. Only 100,000 are considered severe. Our market analysis for Alpha-Antitrypsin considered usage by 75,000 patients, or 75% of the severe sufferers. As this market level is achieved, it is possible that many less severe sufferers will consider usage.

For the initial market analysis, a 25% market achievement was defined as a baseline.

The market potential of any EOS product is driven by the severity of the disease being treated and total number of patients. Figure 4.1-2 presents the market value of EOS products as a function of the number of products in use. The values presented are for 25% of the annual domestic market. As noted previously, the 75% annual market value is $7.2 billion. If a worldwide market is postulated, based on population, the annual value would be $140 billion. In a more conservative estimate, based on the ratio of the GNP of the United States and the GNP of noncommunist Europe plus Japan, the market could still amount to almost $20 billion.

The number of EOS factories required to supply a sufficient quantity of pharmaceutical products to meet 25% of the domestic demand varies for unmanned and manned applications. Figure 4.1-3 summarizes the number of factories required, depending upon the number of products to be produced and the mode of flight operation. The larger number of factories for unmanned applications is a function of design characteristics and electrical power levels. While the design and operational life have improved significantly for avionic systems, the same cannot be said for mechanical and hydraulic systems, which are a large part of the EOS systems. The Shuttle-only concept does not appear to be feasible due to its limited time in space (two man-days/user assumed) and the limited number of sortie flight opportunities that will be available.

FIGURE 4.1-2

ANNUAL MARKET POTENTIAL FOR ELECTROPHORESIS

VGB277-5

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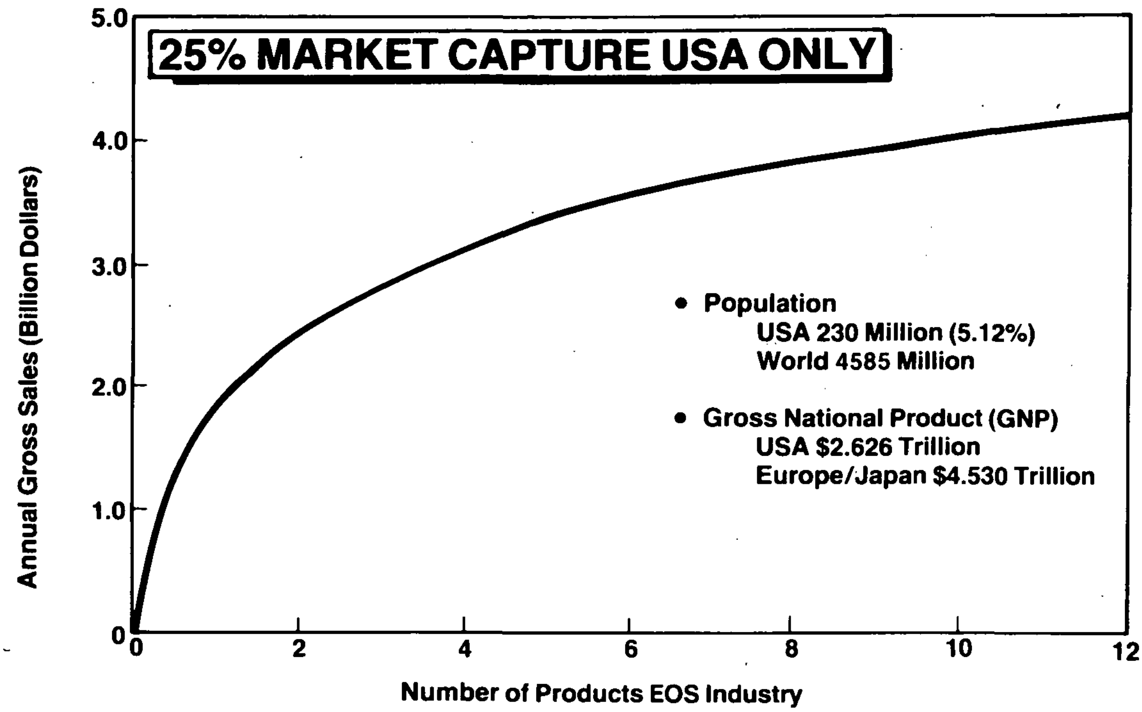


FIGURE 4.1-3

NUMBER OF EOS FACTORIES REQUIRED

25% MARKET CAPTURE

VGB330

MCDONNELL DOUGLAS

Mode of Operation	Number of Factories Required		
	1 Product Industry	6 Product Industry	12 Product Industry
• Shuttle Sortie Only	(a)	(a)	(a)
• Shuttle + Unmanned Platform	3	5	< 200
• Shuttle + Manned Space Station	2	3	< 100

(a) Not Feasible Based on Number of Sortie Flight Opportunities That Will Be Available

Figure 4.1-4 summarizes the operational and support demands that would result in each mode of operation for a one-product and for a six-product facility. Other requirements imposed upon a space station by EOS are as follows:

- Data rate capability of one kilobit/sec required
- G levels less than 10^{-3} g desired during production, 3×10^{-3} g for 6 minutes is acceptable
- 6.4 kW/factory rejected to coolant loop during operation
- Fluid (seven lines) and electrical (40 pins) interfaces required to mate resupply module with internally mounted EOS components
- Docking provisions for resupply module required
- Life support and living quarters for up to two mission specialists required

FIGURE 4.1-4

MCDONNELL DOUGLAS

EOS INDUSTRY REQUIREMENTS
25% MARKET CAPTURE

VGB331

Industry Size	Industry Requirement	Mode of Operation: Shuttle Sortie Alone	Shuttle Sortie + Unmanned Payload	Shuttle Sortie + Space Station
1 Product Industry	Number of Factories	2	3	2
	Weight of Factories, Lb	10,000	15,000	10,000
	Annual Resupply Weights, Lb	0	38,100	22,800
	Orbit Days Needed Per Year	365	365	365
	Electrical Power, kW	11.2	10.5	12.8
	Data Rate, KBPS	1	1	1
	Number Shuttle Flights/Yr	50(1)	6(2)	4
	Crew Size	1 Part Time	As Required for EVA Service/Repair	1 Specialist (3)
6 Product Industry	Number of Factories	(Impractical to Support EOS Industry With Present Shuttle Fleet and Orbit Stay Time)	5	3
	Weight of Factories, Lb		25,000	15,000
	Annual Resupply Weights, Lb		63,500	34,200
	Orbit Days Needed Per Year		365	365
	Electrical Power, kW		17.5	19.2
	Data Rate, KBPS		1	1
	Number Shuttle Flights/Yr		10(2)	6
	Crew Size		As Required for EVA Service/Repair	1-2 Specialists (3)

(1) 7-Day Sortie Duration
(2) Not Including Unscheduled Maintenance and Repair
(3) Part Time if Factory is Not Continuously Manned

The development schedule for a pharmaceutical product will vary, depending on the specific product's properties, use, prior state of development, etc. However, a typical schedule is about 5 years. This time allows for market research, product development, clinical programs, and production verification. For EOS products, it is probable that some space production will be required to conduct the clinical programs. In most cases, this can be accomplished using the Shuttle payload bay EOS facility. With this being the case, then only product verification requires concurrent development and interface between the product and the production facility development.

Figure 4.1-5 illustrates the steps planned in proceeding toward commercial operations. The initial steps toward developing EOS are not predicated on the final commercial platform. MDAC is developing an EOS production facility (Figure 4.1-6) that will fly in the payload bay of the Space Shuttle. It is intended that this space factory provide clinical samples for several products and then produce limited quantities of these products for commercial sales. This production facility will also serve as the prototype for the later space

FIGURE 4.1-5

STEPS TO COMMERCIAL OPERATIONS

EOS GROUND DEVELOPMENT INITIATED 1977

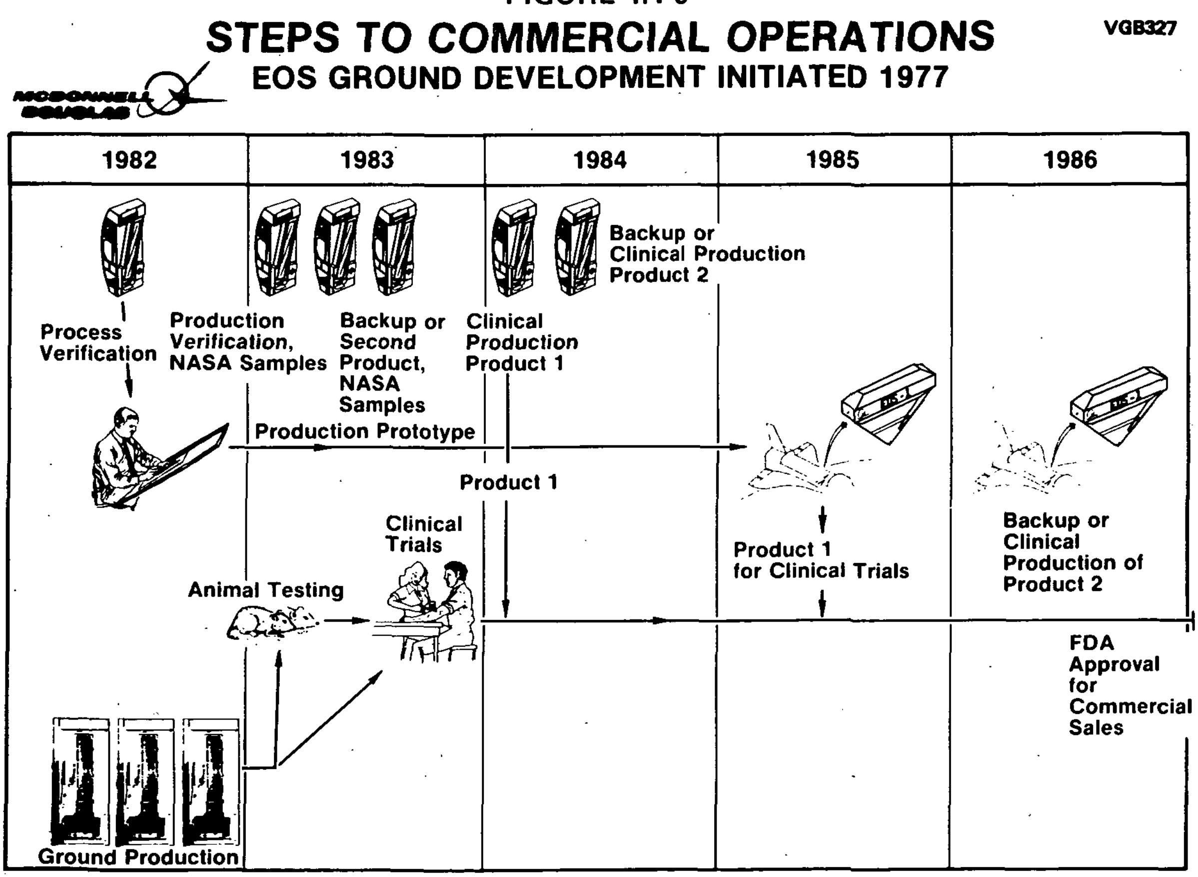
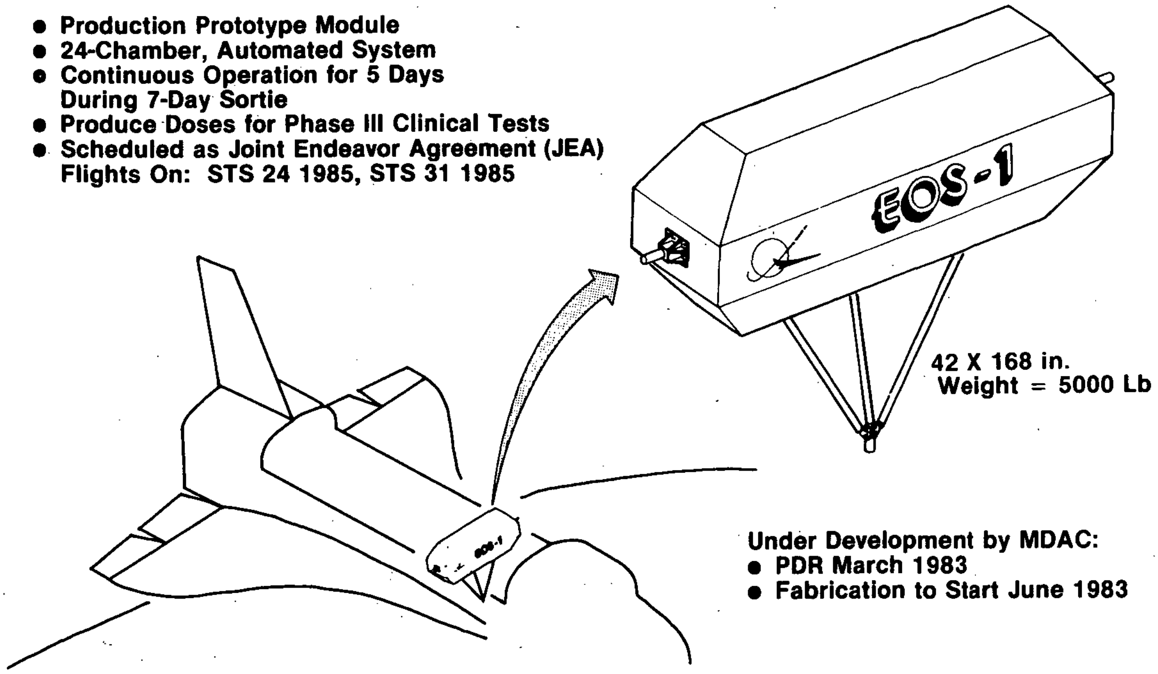


FIGURE 4.1-6

EOS PAYLOAD BAY CONFIGURATION

VGB328

- Production Prototype Module
- 24-Chamber, Automated System
- Continuous Operation for 5 Days During 7-Day Sortie
- Produce Doses for Phase III Clinical Tests
- Scheduled as Joint Endeavor Agreement (JEA) Flights On: STS 24 1985, STS 31 1985



Under Development by MDAC:
- PDR March 1983
- Fabrication to Start June 1983

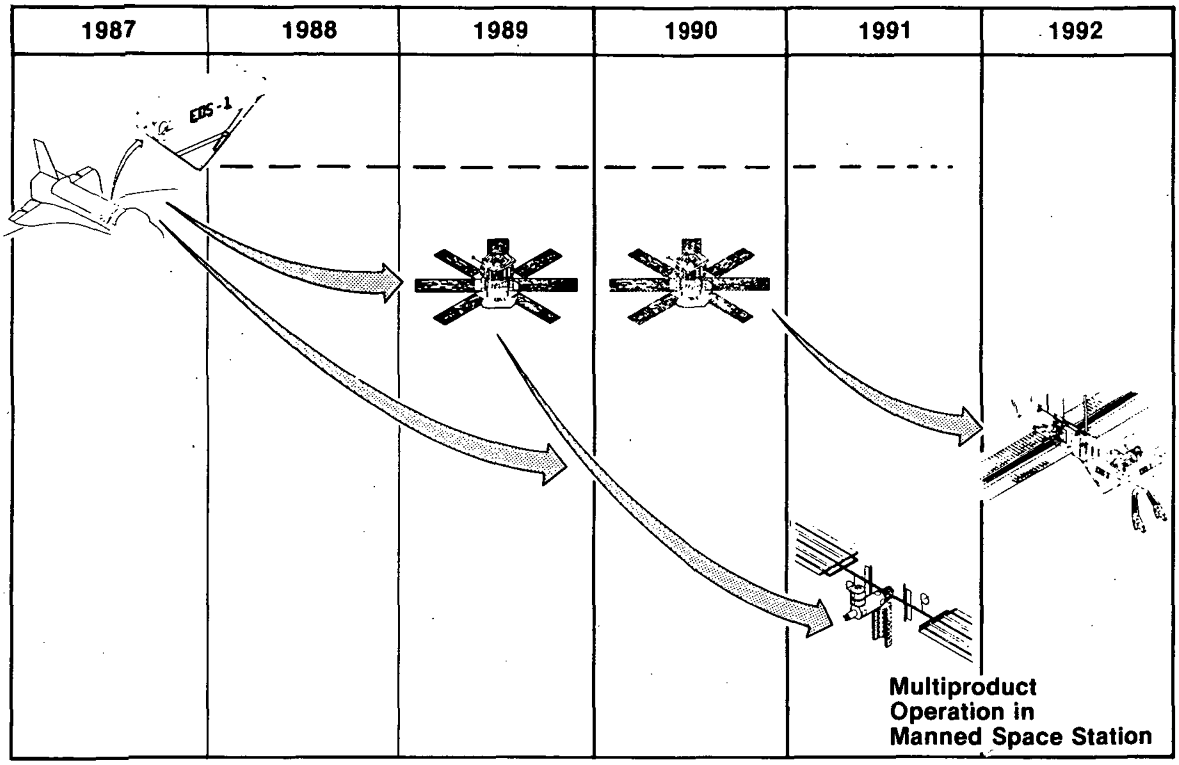
production facility--whether it is to be located in a manned or unmanned spacecraft configuration.

The long-range commercial alternatives are much more difficult to define than the initial operational capability. Neither manned nor unmanned platforms capable of supplying the large power requirements of EOS are firmly scheduled for launch at the present time. For planning purposes, it has been postulated that an unmanned system, capable of supporting EOS, will commence operations in 1989, and a manned space station with like capabilities will become operational in 1991 (Figure 4.1-7).

If an unmanned platform is selected as the EOS baseline, commercial operations could commence in 1989-1990. If a manned space station becomes the EOS baseline, commercial operations will probably not commence until after 1991.

As noted previously, the number of products introduced and the market share achieved by each are major drivers in the annual sales that can be achieved by

COMMERCIAL OPERATIONS ALTERNATIVES



EOS. The schedule or time when these sales are made is dependent on the EOS platform selection. An unmanned platform can bring quicker returns, but the slower buildup and greater quantities of production facilities required slow the product return such that peak annual sales will be achieved at about the same time for both the manned and unmanned concepts.

Pharmaceutical product development and space production facilities to produce these products can be developed in parallel. Actually, the two developments are almost independent, except for the production verification.

Also of importance in this analysis is the fact that several products can be processed by one production facility. This results in a significant reduction in the total number of production facilities.

It is significant to note that current EOS development is outpacing the development of advanced space facilities. Until dedicated facilities are available, it will be necessary to fly as a payload of opportunity on the orbiter. Unfortunately this will not provide enough sustained production of material to allow a commercially viable market to develop. It is essential that a predictable schedule and lower cost per production hour be established if this market is to be satisfied. Current state of the art in EOS favors a manned space station because of its application for all phases of pharmaceutical product development, including the relatively easy expansion of product lines to service already identified markets.

4.1.2 The Role of Manned Systems in Space Manufacturing

Commercial missions in particular will be sensitive to risk of failure, and such mission risks will have a significant impact on the willingness of private venture capitalists to invest in space systems. This will be especially true in manufacturing processes where profits and value will be determined by the quality of the product produced.

Of the manufacturing processes examined to date, EOS provides one of the best illustrations of how direct human involvement can minimize the risk to sponsors.

Electrophoresis involves the use of a complex plumbing system with an inherent leakage problem. Leaks in the system are extremely difficult to detect with automated equipment. The system requires constant refrigeration to prevent product deterioration. The process is also characterized by dynamic instability, which requires continuous periodic adjustment of the system's operating parameters.

Minimal requirements for human assistance in EOS operations include: (a) initiating system operation, (b) monitoring system operation, (c) intervention via the system automation interface when software and/or suspected hardware errors occur, (d) product supply/resupply/change operations, and (e) shutting the system down. Human tasks that would increase process efficiency and minimize the impact of system failures include: (a) fault diagnosis, (b) leak detection/repair, (c) quality control, and (d) materials handling/product storage. All of these tasks can and are being accomplished to some degree via automation. But, the approaches are expensive and of unknown reliability at this time. The presence of a human operator would ensure reliable operation and boost processing efficiency. In addition, some future research and development and product production involving live cells cannot be accomplished without a qualified mission specialist on board.

Figure 4.1-8 summarizes those EOS operational functions for which a human operator is required or desired.

FIGURE 4.1-8

EOS OPERATIONS

MCDONNELL DOUGLAS

VGB349

MAN REQUIRED FOR:

- Deployment/Replacement
- Supply/Resupply
- Maintenance/Servicing
- Product Change
- Sequential Multiproducts
- Live Cell Handling
- Faster Product Development
- New Product R & D
- Fast Response to Emergencies (R & D)
- Innovative Solutions

MAN DESIRED FOR:

- Access Buffering
- Lower System Cost
- Reduced Product Loss
- Reduced System Complexity
- Simplified Logistics
- Simplified Product Storage
- Increased Profit Margin
- Easier Sterilization
- Easier Quality Control
- Easier Maintainability/Leak Detection
- Easier System Diagnostics
- Minimal Down Time
- Batch Processing
- Product Assays

- **Man is the Only Real-Time System Capable of Accepting and Operating on Asynchronous and Nonsequential Input Data**

- **The Overall Cost and Effectiveness of EOS Operations Will be Directly Influenced by the Level of Human Involvement and Productivity**

The first orbital flight of a prototype EOS facility occurred on STS-4 (Figure 4.1-9). The equipment was located in the mid-deck of the orbiter and was accessible to the space crew for scheduled and unscheduled tasks. Scheduled crew activities (Figure 4.1-10) included cycling the power on and off, starting and stopping the system operation, initializing (zero check), processing the sample product, and collecting the product. In addition, photographs of the columnar flow required for later ground analysis were taken 14 times per day. The operator was also required to change the sample input and to change the collection trays.

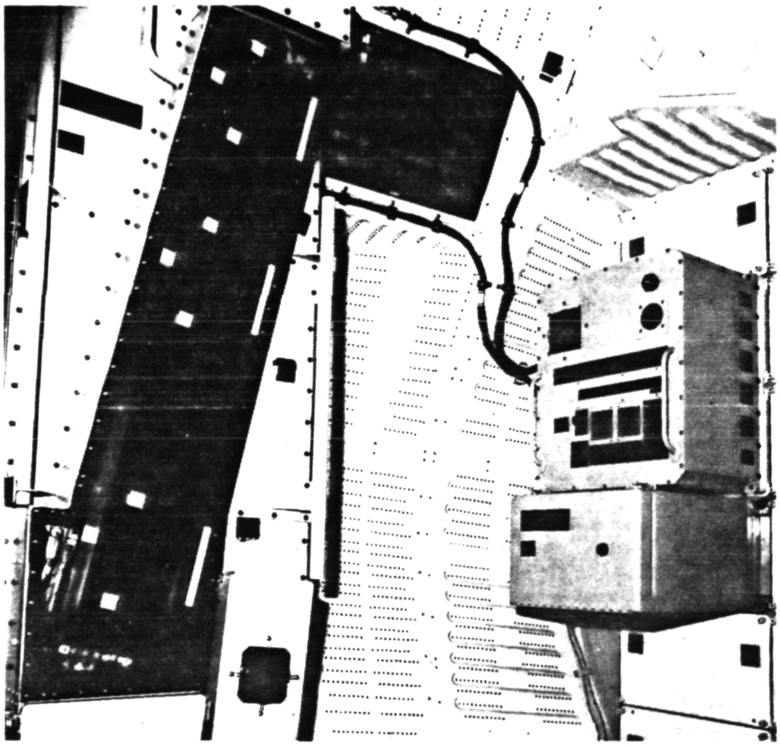
In the separation process, monitoring of the product stream requires considerable skill on the part of the operator to recognize and interpret the flow pattern. While the use of dye simplifies this task somewhat, such additives may not be desirable in processing certain types of products. The bandwidth

MCDONNELL DOUGLAS

FIGURE 4.1-9

VGB314

EOS MIDDECK SYSTEM



Joint Endeavor Agreement

STS	Flight Dates		
4	July	1982	(Completed)
6	April	1983	
7	June	1983	
8	August	1983	
12	March	1984	
16	July	1984	

Results From STS 4

1. Yield Increased 500 Times
2. Repeatable Quantitative Separation Demonstrated
3. EOS Design Concept Validated
4. Value Manned Participation Confirmed

FIGURE 4.1-10

EOS HUMAN OPERATORS ACTIVITY SHUTTLE MIDDECK TASKS

VGB371

MCDONNELL DOUGLAS

SCHEDULED OPERATOR CALLS

Perform as Power Loadmaster

- Cycle Power On/Off as Required

Change System Operation

- Start/Stop
- Zero Check
- Process Sample
- Collect Sample

Take Photographs of Column

- Required 14X Each Day

Process Maintenance/Service

- Change Sample Input
- Change Collection Trays

Product Stream Detection

- Observation is Possible but a Highly Skilled Mission Specialist is Required to Recognize and Interpret Pattern if Dye is Not Included With the Sample. Current Astronaut Training is Insufficient for Effective use of Information Obtained From Column Observation
- Shuttle Link to Ground-Based Mission Specialist Lacks Adequate Bandwidth for Useful Interaction Between Astronautics and Ground

Five Malfunctions Occurred During the STS-4 Flight, Four Process Out-of-Range Errors and a Mandatory Stop/Reset/ Restart Software Problem. These Incidents Coupled With the Limited Ground Link Indicate That an Onboard Mission Specialist Would Significantly Increase the Efficiency of EOS Operations on Future Flights

required to transmit sufficiently detailed real-time images of this process to a remote control station would place a heavy burden on the TDRSS system.

During the STS-4 flight, five unscheduled malfunctions occurred requiring human intervention. Four were process-out-of-range errors and one was a mandatory Stop/Reset/Restart software problem. The presence of an onboard operator provided rapid resolution of these problems and gave a graphic illustration of the value of direct human intervention in maintaining the efficiency of EOS operations. Market projections suggest that the market for EOS products may easily be in the billion dollar range. If even only a fraction of this potential market is captured, the payoff potential is still so high that the premium for mission success mandates the direct involvement of a human operator to protect the initial investment, increase the operational efficiency, and thereby maximize the dollar return to the sponsors of the mission.

In addition to the specific malfunctions that occurred on STS-4, a number of other unscheduled operator calls occurred. Figure 4.1-11 summarizes the

FIGURE 4.1-11

EOS HUMAN OPERATOR ACTIVITY SHUTTLE MIDDECK TASKS

VGB350

Unscheduled Operator Calls

- Computer Data Logger Memory Full
  - Log Parameter Changes
  - Inform Ground Via Voice Link
- Parameter Out of Operating Range
  - Clear Parameter Warning Indicator
    - This Operation Inhibits all Future Calls Related to the Parameter
  - Log Condition
  - Inform Ground Via Voice Link
- Control Decision Point
  - Sensor Malfunction?
  - Unacceptable Process Condition?
  - Ignore?
  - Attempt System Reset/Restart?
  - Shut Down System?

On STS-4, Two Out-of-Range Errors Were Logged Each Day But None Were Reported to the Ground. Presumably Due to the Ground Link Bandwidth Problems

STS-4 Also Required a System Shutdown/Reset/Restart on the Second Day Due to a Software Problem. An Onboard Mission Specialist for Future Flights Would Provide Immediate Fixes for Problems Such as These and Increase EOS Operations Efficiency

classes of unscheduled calls that could occur and Figure 4.1-12 summarizes the actual numbers of scheduled and unscheduled calls that occurred during the 6.5-hour period of operations on 28 June 1982 and during the 8-hour period of operation on 30 June 1982. Prototype production facilities to be installed in the orbiter cargo bay are currently in the conceptual design phase and are being designed to operate continuously for 5 days. Longer operating periods of 30 days or more can be anticipated when free-flying platforms or manned space stations become operational. With these longer missions, the probability of unscheduled operator calls becomes progressively higher.

Due to the functional complexity and dynamic qualifies of the EOS process, the presence of a human operator can have significant economic impact upon operations. An onboard mission specialist can contribute in the following areas:

- As the operator/monitor which even fully automated systems would still require to some degree.

FIGURE 4.1-12

STS-4 EOS OPERATIONS SUMMARY

VGB351

MCDONNELL DOUGLAS

	28 June 1982	30 June 1982
Raw Parameters		
Total Operating Time	6.5 Hours	8 Hours
Total Number of CPU Operator Calls	27	28
Scheduled Calls	19	22
Unscheduled Calls	8	6
Total Number of Key-Board Inputs Required	99	83
Scheduled Calls	48	72
Unscheduled Calls	51	11
Averaged parameters		
Operator Calls/Hour	4	3
Scheduled Calls	3	3
Unscheduled Calls	1	1
Keyboard Inputs/Hour	15	10
Scheduled Calls	3	3
Unscheduled Calls	6	2
Operator Call Response Time	27 Sec	43.7 Sec

Manned Presence Essential to Reduce Risk of Failure

- As a schedule compressor in research and development activities, contributing to reduced costs and risks while promoting milestone achievement.
- As a specialized programmable sensor with unique perceptual abilities, contributing to improved process control, fault diagnosis, leak detection, and servicing/repair functions. Over a 10-year period, human caretaker activities could yield an eightfold reduction in product development time while increasing product throughput by a factor of five.
- As a buffering shield, minimizing the impact of unknowns and the unexpected while protecting access to proprietary information.

In summary, the complexity of the separation and storage processes and equipment for longer-duration EOS systems is such that the automatic control and robotic operation may be an unreasonable goal. The <u>risk</u> of malfunction and product loss compared to the potential return-on-investment will be a key criterion in the decision between manned and robotic systems for these future systems.

4.2 SPACE COMMUNICATIONS

Society can be classified in terms of preindustrial, industrial, and post-industrial development. Most of the work today is essentially preindustrial and is engaged in extractive work: mining, fishing, timber, and agriculture. For industrial societies, the majority of the labor force engages primarily in industry and manufacturing. The U.S. is typical of the postindustrial type of society in that the majority of the labor force is engaged essentially in services--that is, trade, finance, education, research, administration, and government.

Accordingly, communication is, and will continue to be, an important segment of our everyday life. In a research program at the Bell Telephone Laboratories, E. T. Klemmer* observed activity patterns of more than 3000 persons during their working day. On the average, the people in Klemmer's study were found to have spent over two-thirds of their time in some form of communication. This finding is believed typical of modern industrial and post-industrial societies, and it is not expected that communication-related activities will diminish in the foreseeable future. This means that communication will continue to occupy a significant portion of our working time in the coming decades regardless of whether we work at remote stations, at home, or in large industrial-technical complexes.

As more of the countries of the world progress from preindustrial into industrial and postindustrial society, their needs for such fundamentals as equality, liberty, health, education, income, and power will grow irrepressibly and irreversibly. The facilities for communications must expand to meet this growing demand.

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*Reported in: Chapanis, A., Prelude to 2001: Exploration in Human Communications, Johns Hopkins University, April 1971.

4.2.1 The Growing Market for Space Communications

Inasmuch as it is people who communicate with people, it is reasonable to base the current and projected future needs for communications-related services on population statistics. Figure 4.2-1 tabulates some basic demographic and economic indicators. Estimates are included for the 1982 calendar year, with trends projected to the year 2000. The source of these data is the Population Reference Bureau, which gathers, interprets, and publishes information on the facts and implications of national and world population trends. Headquartered in Washington, D.C., the Bureau is a private, nonprofit, educational organization that consults with other groups and operates an international program and information service.

The Bureau publishes annually the World Population Data Sheet, summarizing demographic statistics by region and listing all geopolitical entities with a population larger than 200,000. Data available for 1982 from the sheet include current population estimates, population projection to 2000, and per capita gross national product.

The total world population, as estimated by the Bureau, will increase about 1.5 billion from a mid-1982 total of 4585 million, to a year 2000 total of 6053 million (Figure 4.2-2). This growth in world population would result in a real increase in gross national product (GNP) in proportion to the relative population increase. Assuming no regional growth in GNP per capita (which represents maintenance of the status quo), net estimated increase in population multiplied by the average GNP for each region equates to the increase in GNP as shown in the fifth column on the chart. The sum total for the seven regions would amount to $2095 billion over the next 18 years. On the other hand, the worldwide average GNP per capita amounts to $2620 per person. If this average were achieved by every region, considering the 1468 million increase in population by the year 2000, some $3846 billion would be added to the GNP. This would result, for example, if the developing regions such as Asia and Africa experienced a real increase in total GNP along with their expected increase in population. The most likely increase in GNP can be assumed to fall somewhere between the $2095 and $3846 billion figures.

FIGURE 4.2-1

WORLD POPULATION AND GNP 1982-2000

MCDONNELL DOUGLAS VGB317

Geographical Region	Population — Millions			Gross National Product		
	1982	2000	Increase	Per Capita ($)	Increase ($)	X3% (1) ($)
Africa	498	847	349 (24%)	770	269B	8 B
Asia	2671	3528	857 (58%)	920	788B	24 B
North America	256	286	30 (>2%)	11240	337B	10 B
Latin America	378	549	171 (12%)	1910	327B	10 B
Europe	488	511	23 (2%)	7990	183B	6 B
USSR	270	302	32 (>2%)	4550	146 B	4 B
Oceania	24	30	6 (<1%)	7600	45B	1 B
Total World	4585	6053	1468 (100%)	2620	2095 B	63B (2)
					3846 B	115B (3)

B — Billions $ — USA Dollars (1980)

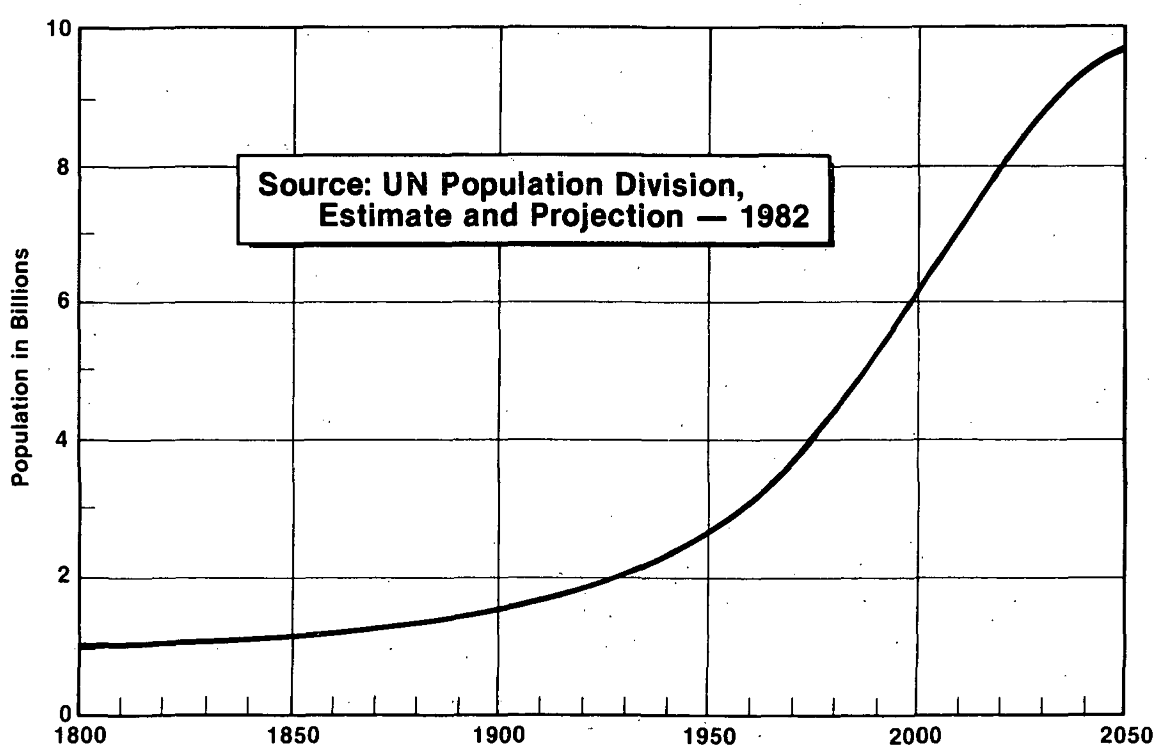
Notes:
(1) Based on BEA Input/Output Tables for Communications-Oriented Industries
(2) Column Total
(3) Row Calculation
Source: World Population Data Sheet, Population Reference Bureau, Washington, DC 1982

MCDONNELL DOUGLAS

FIGURE 4.2-2

VGB316

WORLD POPULATION 1800-2050



As pioneered by Leontief[1, 2] and supported by many economists, an "input-output" technique has been developed to analyze and to measure the interrelationships between various producing and consuming factors within a national economy. Using the input-output structure of the U.S. economy as a model[3], it has been determined that about 3% of the GNP is made up of industries providing communications-related goods and services.

Limited studies of other nations' economies have shown them to be similar to the U.S. input-output structure, which means that the above-stated fraction of communications-related GNP to the total GNP would probably hold true elsewhere.

Using the 3% figure, by the year 2000, on a worldwide basis, between a $63-billion and $115-billion-per-annum increase can be expected in communications-related goods and services. In absolute terms, the figures represent a major market opportunity for new communications goods and services.

For 36 nations representing each of the seven regions of the world, statistics for GNP and number of telephones in use are plotted in Figure 4.2-3. Also shown is the world total of $6.2 trillion GNP and 350 million telephones in use as of 1978. The postindustrial U.S., representing a GNP of about $1.5 trillion and using about 142 million telephones, dominates all other regions and nations. Statistically, there is a high degree of correlation (0.98) between the two parameters shown on the chart. Therefore, it is possible to derive an expression relating the number of telephones to GNP. Since GNP is also a function of population, an increase in demand for telephones also can be expected to be experienced for an increase in real population.

For the total world, 90 additional telephones are required for each GNP increment of $1 million. The world GNP can be projected to increase somewhere between $2.1 and $3.8 trillion over the next 28 years. On the basis of 90 telephones per $1 million, this increase in GNP would equate to a range of 189 million to 342 million telephones.

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[1] The Structure of American Economy, 1919-1929; W. W. Leontief, Harvard University Press, 1941.

[2] Input-output Economics, W. W. Leontief, Oxford University Press, 1966.

[3] Revised Input-output Tables for the United States: 1967, Bureau of Economic Analysis Staff, Page 29, June 1977.

FIGURE 4.2-3

VGB376

TELEPHONES IN USE — 1978

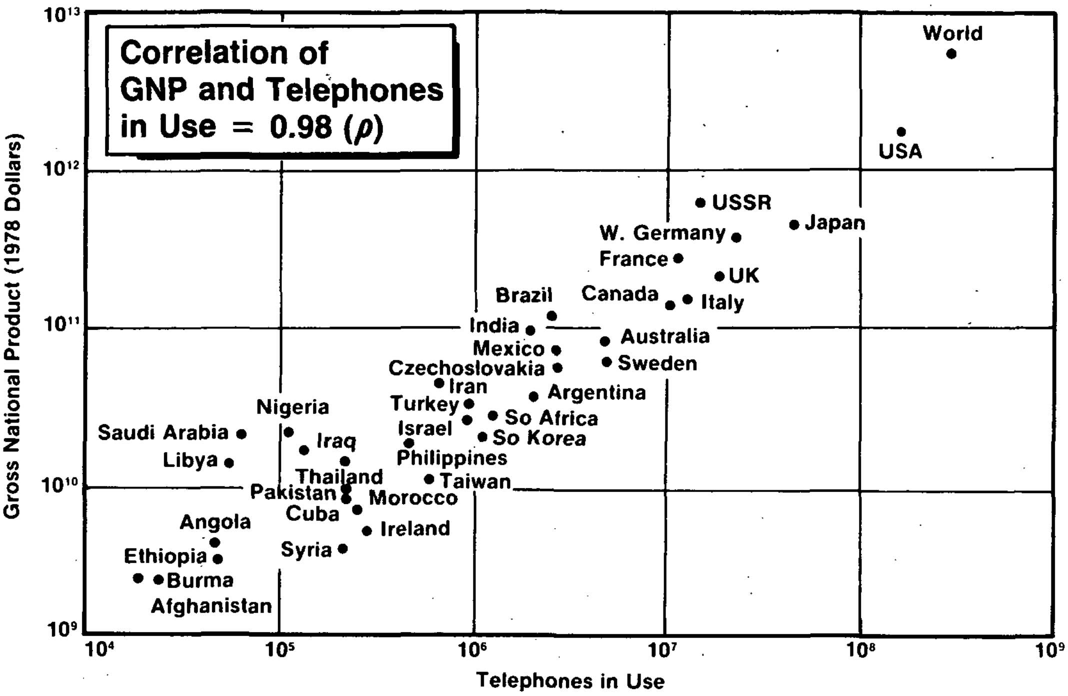


Figure 4.2-4 plots historical trends in the growth of telephone service. The trends for seven countries and the world in total were based upon data documented by the Bell Telephone System in the year 1940 and by statistics provided by the 1982 issue of the Statistical Abstract of the United States (which also includes selected statistics of other nations) published by the U.S. Department of Commerce.

The historical worldwide annual growth in telephone service between the years 1940 and 1978 was about 4%, the same growth rate as was observed for the U.S. and Sweden. Japan experienced an 8% growth during the same period, which reflects the rapid industrial and economic growth of that country.

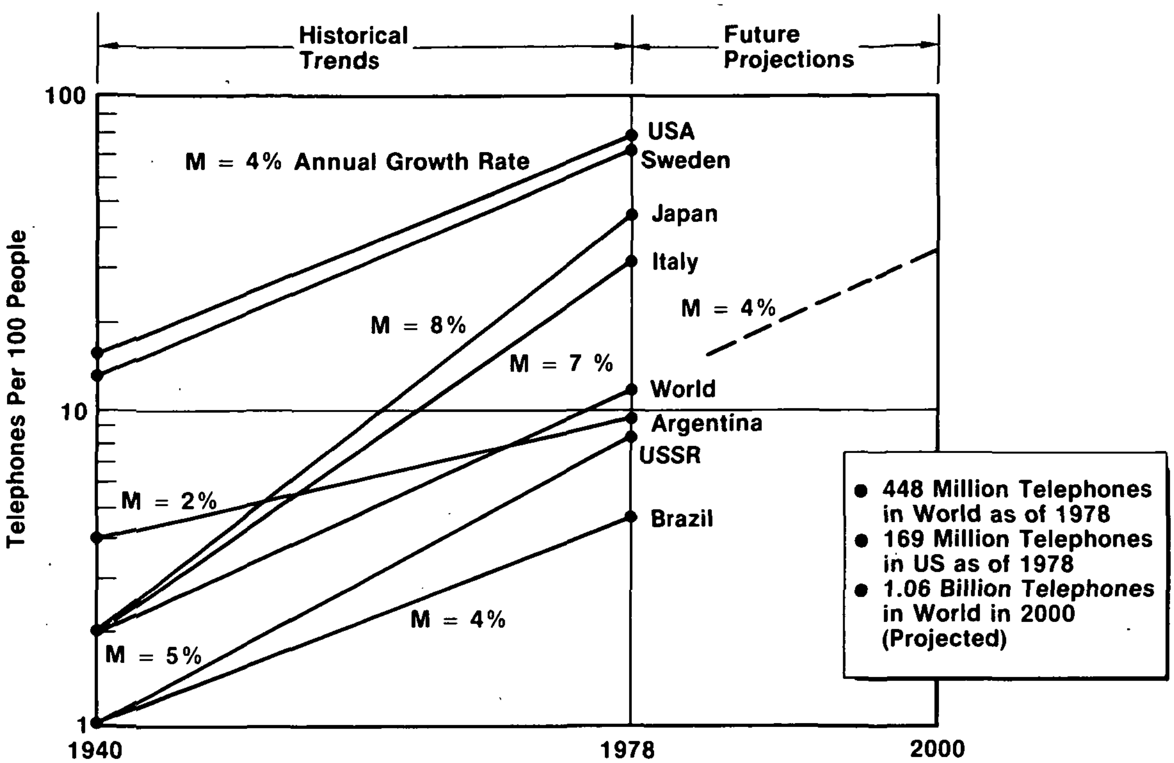
A reasonable world future growth rate of 4% was projected to continue to the year 2000. An increase in telephones from 11 to 32 per hundred will be realized if this 4% growth trend continues.

As pointed out in an earlier chart, telephones and GNP correlate closely. Therefore, an index number based upon "telephones per 100 capita" would be representative of real economic growth normalized against population increase.

FIGURE 4.2-4

TELEPHONE SERVICE GROWTH IN THE WORLD

VGB318



Source: Statistical Abstract of the United States, 1982, US Government Printing Office

There is an imbalance in the status quo with regard to the number of telephones in use and the distribution of the world population. A pictorial representation of this situation is shown on Figure 4.2-5.

The solid curve on the chart represents the number of people that can be serviced from a given geosynchronous equatorial orbital position. For example, near 20° east longitude, where the nadir point would correspond roughly to Brazzaville, the capital of the Congo, some 2 billion people, or one-half the present world's population, would be within the range of satellite telecommunications. The dotted curve, representing the number of telephones with that range, shows that fewer than 100 million out of a total of 350 million telephones worldwide could be serviced. A contrasting situation is shown at 200° east longitude near Jarvis Island in the central Pacific Ocean. Here, the same number of telephones are seen, but the population in view has fallen below 500 million.

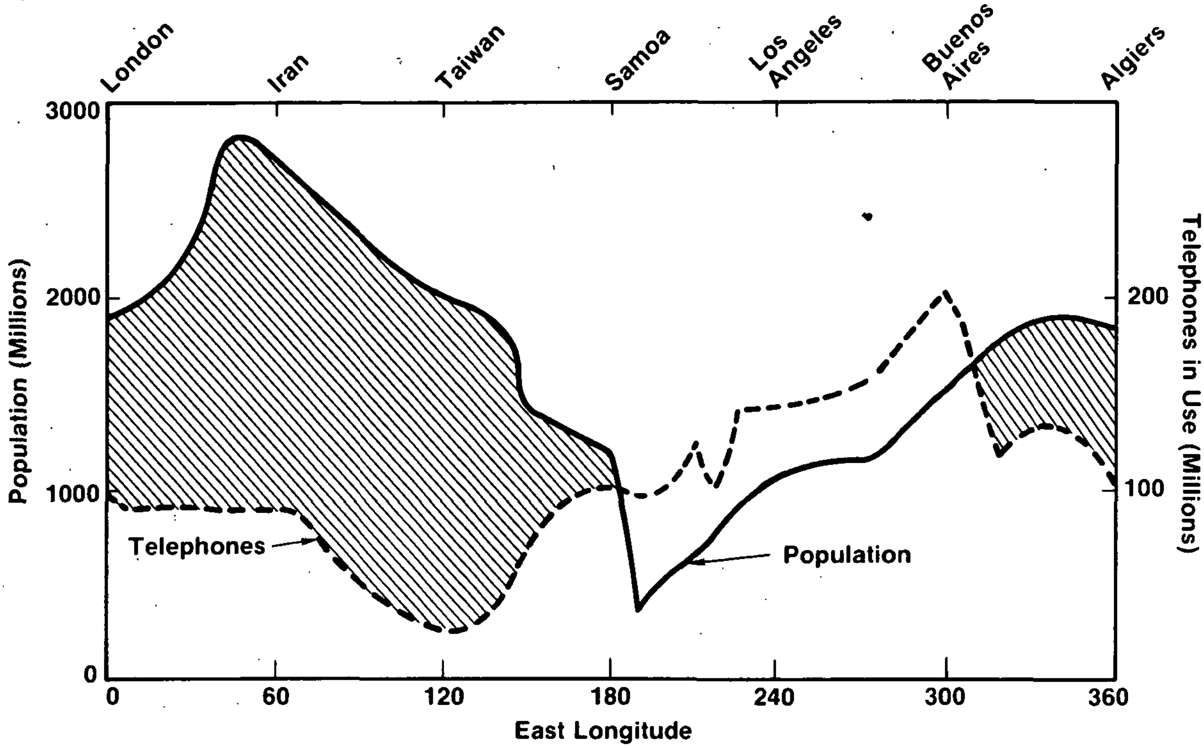
The shaded portion of the chart represents geographical regions where fewer telephones exist than the population would demand. A compounding factor in

FIGURE 4.2-5

POPULATION AND TELEPHONES AS SEEN FROM GEOSTATIONARY ORBIT

VGB377

MCDONNELL DOUGLAS



Source: R. S. Magnant, Domestic Satellite: An FCC Giant Step, 1977

this imbalance is the projected population increase in these very regions. The opposite is true for the American continents. In these regions, largely because of the dominance of the U.S. and Canada, telephones per capita far exceed worldwide averages.

Future adjustments to rectify the imbalance could be achieved more or less rapidly by relying more on satellite telecommunications. However, the satellite parking spots would lie largely within the 1° to 120° east longitude positions. Using standards for domestic U.S. satellites, only 40 such positions would be available. The projected demand to meet an increase in population of some 1.6 billion by the year 2000 would require approximately 150 INTELSAT V class satellites. Current technological limitations add to the severity of this situation.

In 1977, there were seven domestic communications satellites in service over the U.S. Two WESTAR satellites were operated as part of the Western Union network, three COMSTAR satellites (owned by COMSAT Corporation) were leased to the Bell System and GTE, and two RCA SATCOM satellites satisfied the needs of other users. Each satellite provided 24 transponders working in the 6/4-gigahertz portion of the spectrum. These satellites were parked in about 1/3 of the total of 24 orbit positions spaced at 3° longitudinal intervals necessary to minimize interference and maintain elevation angles greater than 10°. The capacity of these seven satellites is plotted as the base point for the year 1977 in Figure 4.2-6. In 1982, there were the equivalent of 360 transponders in operation. Assuming the observed growth reflects the market demand, and projecting this growth rate to the year 2000, it becomes readily apparent that demand will exceed the current technological and political constraints for fixed satellite service. If, in addition, new services are added, such as direct broadcast and other innovations, including electronic mail and teleconferencing, the demand capacity in the 1990s will be an order-of-magnitude greater than the services available. By the year 2000, the projected need would exceed current capacity by some two orders of magnitude.

FIGURE 4.2-6

NORTH AMERICAN DOMSAT DEMAND GROWTH

VGB281

MCDONNELL DOUGLAS

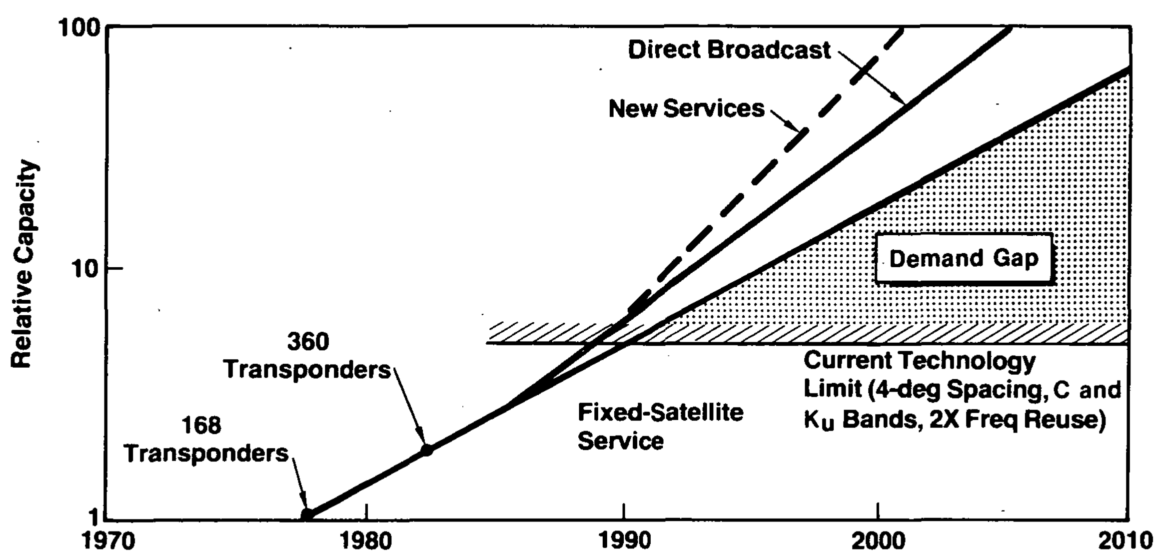


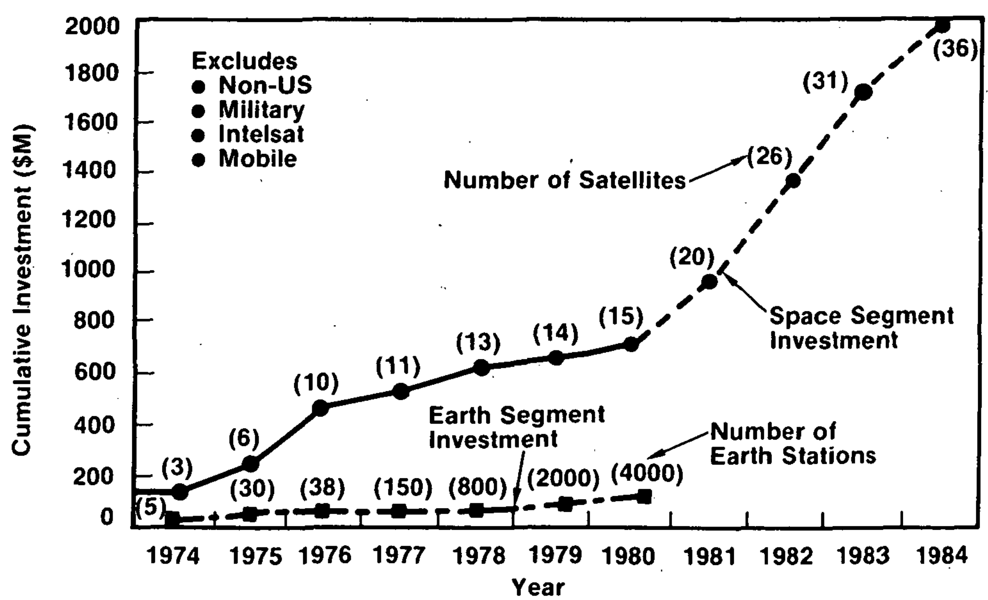
Figure 4.2-7 presents the current and projected cumulative investment in the United States Earth-based and space-based segments of satellite communications systems. The lower curve relates the number and cost of all the Earth stations in the U.S. domestic service. In the earliest years, large and expensive heavy trunk stations costing several million dollars each were installed. Later, the market for receive-only Earth stations developed, and the individual prices of these stations decreased from $100,000 to the present price of $8000 or less.

The resulting Earth station total investment has increased, although it is small in comparison with the investment in the space segment. The total U.S. geosynchronous orbit space investment between 1975 and 1984 will be approximately $2 billion. At the projected rate of growth, the investment will more than double in the next 5 years. If this rate of growth continues into the 1990s, the space segment will represent an investment in the tens of billions of dollars.

FIGURE 4.2-7

VGB378

CUMULATIVE INVESTMENT IN US EARTH AND SPACE SEGMENTS



Source: Walter Morgan, "The Next Decade — An Economic Outlook for the Eighties," Satellite Communications, January 1981

Aside from purely economic considerations, there are technological and political barriers to be overcome in closing the demand gap. Issues of the number of orbital slots that can be allocated and frequency use assignments are issues of a political nature and are resolved through inter-government agencies such as the International Telecommunications Union. The basic problem which must be addressed is to increase, by whatever means necessary, the telecommunications system capacity. Some of the key technology growth directions required for communications satellites are the following:

- Additional frequency bands
- Frequency reuse techniques
  - Orthogonal polarization
  - Spot beams
  - Antenna sidelobe control
  - Improved station-keeping and attitude control
- Better bandwidth utilization
  - Modulation techniques
  - Multiple access techniques
  - Interference tolerance
- Reduced orbit spacing/slot-sharing
  - Improved station-keeping and attitude control
  - Improved Earth terminal antennas

The list is intended to be neither complete nor comprehensive. Rather, it is intended to illustrate the many types of factors that need to be addressed in meeting future demands.

4.2.2 The Role of Manned Systems in Space Communications

Commercial communications satellites today are divided into two categories: (1) spin stabilized and (2) three-axis stabilized. Spin-stabilized satellites to date have been characterized by a spinning cylindrical section with a despun antenna platform and an uncomplicated set of deployments. Three-axis-stabilized satellites have been characterized by a non-rotating bus with unfurlable solar arrays and antennas. The solar arrays and antennas are usually unfurled with a complicated series of deployments before the spacecraft reaches the final on-orbit configuration.

Both types of satellites have been rapidly increasing in size (power, physical size, and capability). This trend has led to increasing complexity of satellites in terms of deployments and more rigid pointing requirements. Good examples are the TDRSS and the INTELSAT 7.

With the development of a manned space station and a low-thrust orbital transfer vehicle (OTV), problems involved with increasing complexity of satellites may be reduced. The space station could act as a spacecraft test bed, allowing final verification of the communications subsystem. Final alignment of antennas and sensors could be completed without the influence of the 1-g environment seen on the Earth. A low-thrust OTV would allow certain deployments to occur under manned observation. In the event of a deployment failure, the problem could be corrected before a final orbit is reached.

With the availability of a space station, then, an opportunity exists to increase the performance and decrease the risk in several areas of commercial communications satellites. The micro-gravity environment may enable commercial satellite builders to test certain subsystems more easily than is currently being done on earth. The non-restricted area may also permit testing that is currently impossible on the ground. The economic motives for space-station testing will depend on the complexity of communications satellites in the future as well as space-station user costs. Figure 4.2-8, summarizes for two classes of missions, <u>technology development</u> and <u>orbital checkout</u>, some of the key contributions that could be made by a manned space station in support of advanced communications systems.

The best authority projects a world population increase of 1.5 billion over the next 18 years. Short of a catastrophe of worldwide proportions, this increase in population represents real increase in market demand and, therefore, in gross national production of between \$63 and \$115 billion annually for the communications-related industries (Figure 4.2-9).

To satisfy this increase in demand, by the year 2000 it will be necessary to manufacture additional equipment and build new plants. The industry average suggests that about \$2.00 of plant and equipment are required to produce \$1.00 of gross revenue. Accordingly, in order to meet the projected increase in

FIGURE 4.2-8

VGB379

SPACE STATION CONTRIBUTIONS TO SATELLITE COMMUNICATIONS GROWTH

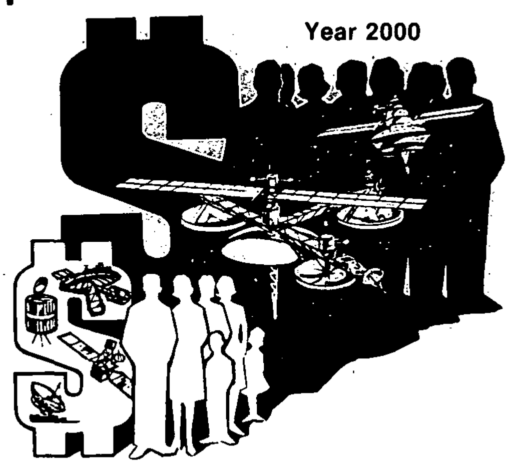
MISSION	KEY STATION CONTRIBUTIONS
Technology Development	
• Propellant Management	• Zero-g, Long Duration, Manned Presence
• Materials Aging/Contamination	• Long Duration, Zero-g
• Antenna Pattern Development	• Zero-g, Absence of Ground Reflections, Manned Presence
• Testing of Deployables	• Zero-g, Manned Presence
• Plume Effects/Characterization	• Zero-g
Orbital Checkout of Operational Spacecraft	
• Final Antenna Alignment	• Zero-g, Manned Presence
• Full or Partial Deployment	• Low-g OTV
• System Test	• Ability to Recover From Postlaunch Failures

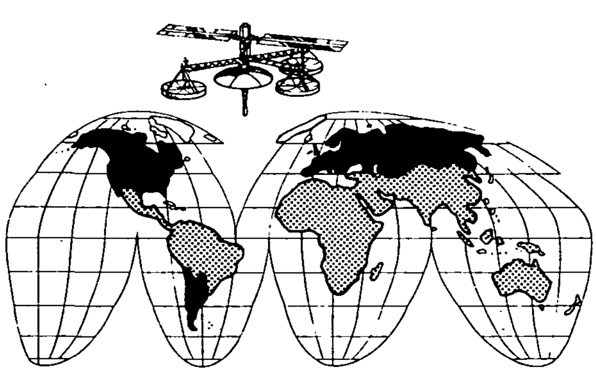
FIGURE 4.2-9

VGB319

COMMENTS ON WORLD MARKET FOR INFORMATION SERVICES

- Increase in Population by 2000 Will Generate New Markets in Communications Related Equipment and Services of $63 to $115 Billion Per year
- Additional Investment in Plant and Equipment Equates to $120 to $230 Billion by 2000
- Developing Nations Advance Socioeconomically Through Domestic Production, Use of Low-Cost Earth Stations and Leasing Circuits From High-Technology Telecommunications Satellites





- US and Developed Nations Benefit by Providing New Space Technology and Systems to Developing Nations

DEVELOPED COUNTRIES
DEVELOPING COUNTRIES
SPARSELY INHABITED ARCTIC ISLANDS

demand, the new plant and equipment which will be required will represent an added capital investment of between $126 and $230 billion. The developed and developing nations must share the burden of this increase, as well as benefit from the return on investment that can be expected.

In the U.S., the industry rate of replacement of telecommunications plant and equipment is about 6% per year. Advances in technology require economically and functionally obsolete systems to be replaced every 17 years. On this basis, the new plant and equipment to meet worldwide needs by the year 2000 represent assets that do not exist today.

New technology can doubly contribute to the general development of both developed and developing nations. The development is "a necessary and irreversible process from the viewpoint both of the hopes of backwards people and of the selfish interests of the advanced."[4] Developing nations can provide domestic production of simple, low-cost subscriber equipment and Earth stations that would provide the revenue with which to lease the linking circuits and services from high-technology, economically favorable telecommunications satellites. On the other hand, the developed nations, and in particular the U.S., can benefit by providing these needed services.

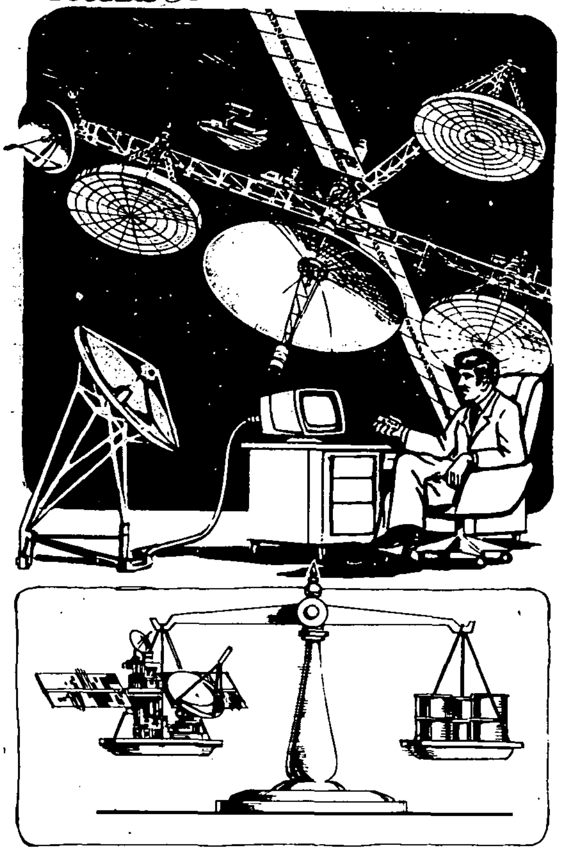
On the basis of the work done to date, two basic recommendations are offered. The first is that this nation should support the expansion of communication services on a global basis (Figure 4.2-10).

Secondly, implementation of this objective requires this nation to encourage, by whatever means possible, the development of the technology and capability to construct platforms in space and to service geosynchronous Information Service Platforms.

The benefit to the United States in supporting these recommendations is that it keeps this nation ahead of competitors in high-technology areas and it provides exportable products and services favorable to a positive long-term balance of trade.

[4] World Order, Rationality and Socioeconomic Development, H. Jaguaribe, DAEDALUS, Volume 95.

FIGURE 4.2-10



THE ROLE OF MANNED SPACE SYSTEMS IN COMMERCIAL COMMUNICATIONS

VGB320

- **Develop Technology to Build and Operate Information Service Platforms**

- **Benefit to the United States:**
  - Keep Ahead of Foreign Competition
  - Export Products and Services Favorable to Balance of Trade
  - Expand Services on Global Basis

- **Advance Key Technology Areas**
  - Microwave Components
  - Large Precision Antennas
  - High Power Capability
  - Space Construction Materials and Methods

4.3 REMOTE SENSING

In general, current remote-sensing satellites such as Landsat D use polar orbits. Japan's MOS-1 will have a circular sun-synchronous 99.1-degree orbit with an orbital period of 103 minutes and altitude of 909 km. The Soviet Meteor Earth Resources Satellite is also polar, with an orbital inclination of 98 degrees, an orbital period of 97.8 minutes, and altitude between 589 and 678 km. High-inclination orbits are especially critical in dealing with major global environmental problems and meteorological patterns. A typical example is to establish the rate of retreat of glaciers as a function of the buildup of carbon dioxide in the amosphere. The vulnerability of the West Antartic ice sheet to environmental changes is well known.[5]

Figure 4.3-1 illustrates the significance of polar observations relative to understanding major climatic changes. Particulate pollution from mid- to high-latitude industrial nations in the northern hemisphere may cause "Arctic haze, "i.e., minute carbon particles, which may cause wholesale melting of the Arctic ice pack. Possible sources and transport routes for these airborne pollutants from mid-latitudes to the Arctic are shown. Major contributor to this pollution is believed to be the Soviet Union, based on manganese and vanadium ratio data.[6]

Inasmuch as polar orbits provide complete Earth coverage, potential users of remote sensing data from polar orbiting satellites represent a broad spectrum of science, government, and private agencies (Table 4.3-1).

Figure 4.3-2 summarizes the categories of users of remote sensing data as of 1983. It is interesting to note that domestic private users represent 56.4% of the clients for remote sensing data.

It is clear that commercialization of remote sensing data will require global coverage. A precessing orbit will permit inspection of specific targets at varying sun angles and nighttime viewing by thermal infrared.

In addition to satellites such as Landsat, data collection platforms (DCPs) will also be used to collect and transmit data to space platforms to indicate

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[5]Washburn, A. L., Focus on Polar Research, Science, Vol 209, Pages 643-652, 1980.

[6]Rahn, K. A. and Shaw, G. E., Arctic Warming Trends, Naval Research Review, Vol 3, 1982.

FIGURE 4.3-1

TRANSPORT OF AIRBORNE POLLUTANTS TO ARCTIC REGIONS

VGB372

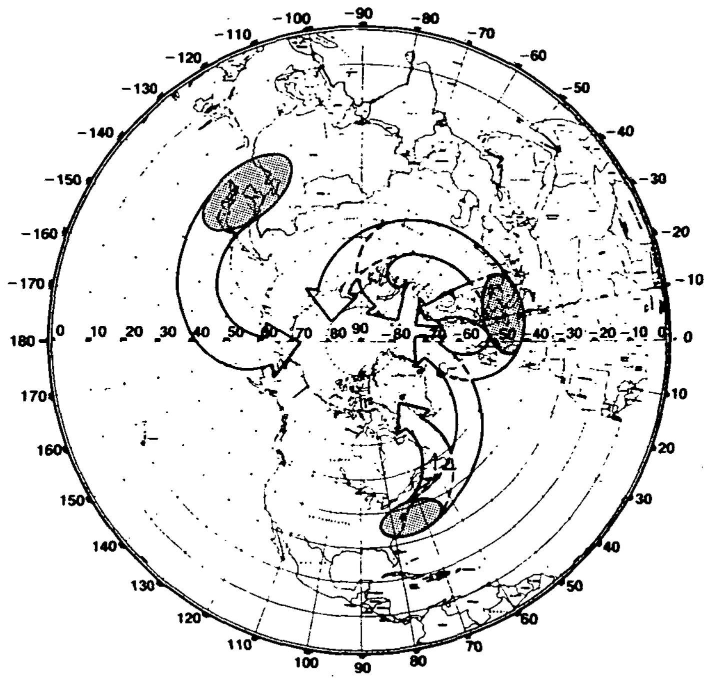
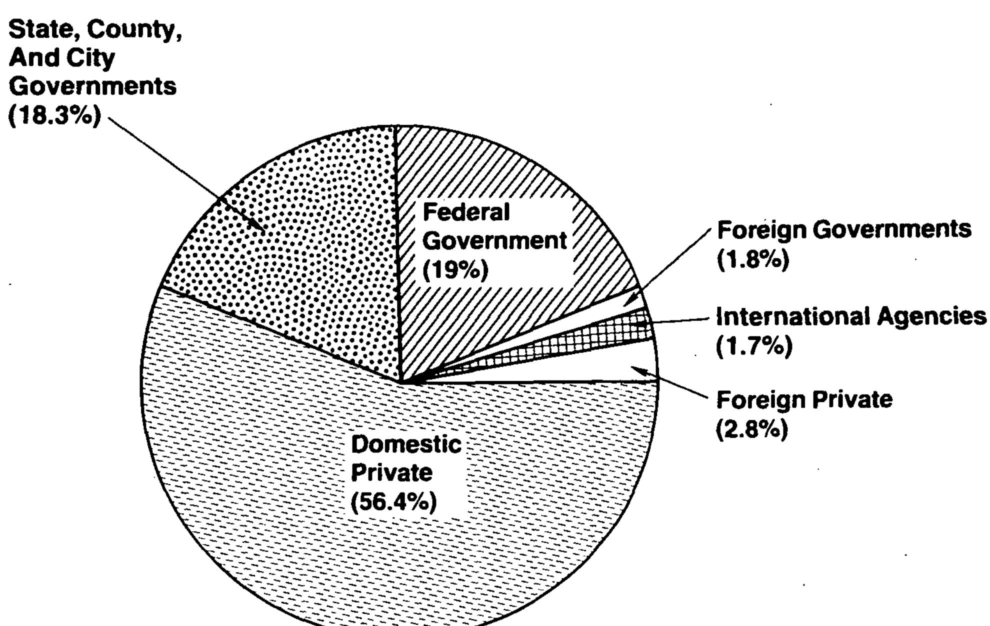


FIGURE 4.3-2

USERS OF EARTH OBSERVATIONS DATA — 1982

VGB278



Adapted from Follet, A.B., Survey of the Professional Committee, American Society of Photogrammetry, Falls Church, VA, 1982

Table 4.3-1. Candidate Uses of Remotely Sensed Data

Land	Ocean
Forest Management	Marine Transportation
Crop Management	Fishing Industry
Water Management	Offshore Drilling
Snow Pack Measurements	Spills and Contaminants Detection
Disease and Insect Control	Erosion Mapping
Demographic Measurements	Tidal Wave and Severe Sea Monitoring
Mineral Surveys	Disaster Warning
Petroleum Surveys	Search and Rescue
Toxic Waste Monitoring	Glacier and Pack Ice Measurements
Land Use Planning	
Mapping	**Atmosphere**
Archeological Surveys	Weather and Climate
Ground Traffic Monitoring	Air Traffic Control
Fire and Flood Detection	Severe Weather Warning
Earthquake and Volcano Prediction	Air Quality Measurement
Disaster Evaluation	Air Transportation Routing
Search and Rescue	Contamination Monitoring

changes in "ground truth"--tilt due to an impending volcanic eruption or other seismic events, stream flow, etc.

By way of an example, comparison of conventional aerial/ground survey techniques and satellite economics and the potential savings that can be realized can be illustrated by a case history taken from Short (1982).[7] Because of desertification in West Africa, it was necessary to relocate nomadic tribes in Upper Volta. Through the International Development Association of the World Bank, Landsat imagery was obtained to show soil types, rain-

[7]Short, N. M., The Landsat Tutorial Workbook, NASA Ref. Publication 1078, NASA, Washington, D.C., Page 553, 1982.

fall, forests, and permanent residents by an appropriate color code. The Landsat-coordinated study took 6 months at a cost given below.

Consultants	
Remote sensing (33 days)	$ 6,950
Soil survey (21 days)	3,150
Computer tape analysis	
Four scenes analyzed	12,000
Photo reproduction	1,400
Cartographic compilation	6,290
Map printing (500 copies)	1,900
	$31,690

Using conventional aerial photography and surface mapping, the study would have taken 2 years at an order-of-magnitude greater cost:

Aircraft rental	$ 50,000
Aerial photos (13,095 frames at scale of 1:20,000)	65,475
Photo rectification	50,000
Photo mosaicing	130,095
Cartographic compilation	15,000
Photo reproduction	1,400
Map printing	1,900
Consultants, at 6 man-months	27,000
	$340,870

The technological success of programs such as Landsat has been phenomenal. From a commercial standpoint, however, the true market has yet to be established.

Five studies on the recommendations for the future commercialization of these activities have been made for presidential or governmental approval. On 15 December 1982 the Cabinet Council on Commerce and Trade (NOAA) deliberated on the transfer of civil space remote sensing to the private sector and sent their conclusions to President Reagan for his decision. Another NOAA study on space commercialization was sent to Congress on 1 February of this year. On 8 March President Reagan announced his decision to transfer the government's weather satellites and land remote-sensing satellites to the private sector. The next step is to obtain legislative approval of the plan. Three non-government reports on this subject by Econ, Inc. (Princeton), EarthSat (Bethesda), and the National Association of Public Administration will be sent to Congress by 1 April 1983.

It has been suggested that it will be necessary to recover $50 million per year to pay for the cost of a Landsat satellite system. Since the land and 200-mile offshore areas of the world come to 200 million square kilometers, a fee of 25 cents per square kilometer of imagery would pay for the system (A. P. Colvocoresses, 1982).[8]

NOAA's 1 January 1983 Thematic Mapper prices are considerably lower. A full Thematic Mapper scene in digital format costs $2800, with a set of computer-compatible tapes that cover seven spectral bands.

Several private companies have expressed interest in pursuing the operation of the current satellite systems as a commercial venture in spite of the fact that actual demand for Landsat data, for example, is relatively small. It has been estimated that less than 0.1% of the current data base has been utilized.

Organizations that are exploring the commercial market for remote sensing data are predicating their projections on the availability of improved sensors as well as the use of multiple sensors to provide data customized to the needs of individual users in a timely and economical fashion.

4.3.1 Projected Developments in the Commercial Uses of Remote Sensing Data

Improvements will continue to be made in current remote sensors, such as the inclusion of multilinear arrays (charge coupled silicon detectors) in multi-

[8] Colvocoresses, A. P., The Economic Feasibility of Operational Earth Sensing from Space, U.S. Geological Survey, Open File Report No. 82-250, 1982.

spectral scanners. Techniques currently being explored to improve performance parameters include:

Data calibration
Edge enhancement
Contrast enhancement
Variance coding
Level slicing
Image smoothing
Noise minimization
Geometric normalization
Artifact cleanup
Edge marking
Skeletonization
Concavity and inclusion filling
Edge thinning
Silhouetting

Within the last 2 years, remarkable advances have been made in computer normalization of remotely sensed data from different satellites at different altitudes and resolutions to produce meaningful composite images. Multiple sensor systems on the same platform can offer improved resolution and stereoscopic coverage. Artificial intelligence may be of limited value in formulating the optimal combinations of sensory data because specific combinations will be based upon the needs of the specific users and the experiences of their consultants.

As an example of multisensor use for image enhancement, Seasat and Synthetic Aperture Radar can now be superposed, with the different look angles providing augmented data on such geologic features as linears and bedding characteristics.

Interpretation Systems (Cleveland Park) offers a novel system which permits operation in intensity, hue, and saturation instead of red, green, and blue color space. They have combined the 80-meter intensity of brightness of Landsat with the nighttime 600-meter resolution of HCMM (Heat Capacity Mapping Mission) data as the hue component and the daytime thermal IR of HCMM as the saturation component to give interesting images of geological features. The slowly cooling granites could appear as red; the rapidly cooling alluvial deposits would appear as bluish tones.

It is obvious that future remote sensing platforms will make use of advanced versions of what the United States Geological Survey, Texas Instruments, and other firms already have operational today. In addition to all the textbook techniques, computerized image enhancement offers oblique viewing of Landsat scenes combined with topography. The 79-meter resolution provides an "alien" view of Earth terrain with colors or enhancements made possible by computer processing. As of a few weeks ago, according to Dr. W. T. Lehman, Director of Exploration Systems for ARCO Oil and Gas Company, it is possible to simulate a flight up the valley shown at any specified altitude or view angle using a technique developed by Mr. Robert Hall of ESL, Inc., Palo Alto, and illustrated in Figure 4.3-3.

FIGURE 4.3-3

THREE-DIMENSIONAL PERSPECTIVE VIEW OF CROSS CREEK, NABESNA AREA, ALASKA, SUPERPOSING ALTIMETRY AND LANDSAT IMAGERY (USGS)

VGB360

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Any pixel-coded entity can be combined with radar or conventional altimetry to yield three-dimensional perspective views. Today it is done on a Texas Instrument DEC. VAX 11/780 System and the EROS Data Center Interactive Digital Image Manipulation System and a Metric Color Graphic Camera.

Interpretation Systems, Inc., has the capability to display intensity information as a pseudo-3-D graphics image with control of all orientation parameters. The Defense Mapping Agency currently produces relief diagrams from digital terrain tapes showing slope, aspect, and elevations in color-coded patterns.

Beam technologies from an Earth-orbiting platform offer excellent opportunities for compositional mapping of the Earth for exploiting resources. Active sensing systems offer considerable promise. Beam technologies include laser beams. Directed lasers may involve gas, chemical, electron discharge, X-ray, and free-electron lasers. The latter system already is utilized in an optical radar system which can overcome Earth atmosphere transparency problems (Quentron modular laser system, Adelaide, Australia).

Other beam technologies for use in compositional mapping include electron, proton, and neutral particles.

The Luminex method developed by Scintrex, Ltd. is used aboard a helicopter or fixed-wing aircraft in which a high-powered ultraviolet laser is fired at the ground to excite the luminescence of minerals in the target area. Light returning from the target (of 400 cm^2) is viewed by a telescope in the aircraft, recorded in a number of channels, and analyzed. The operation is carried out in full sunlight and from an altitude of 60 meters. The method rejects fluorescence from plants and focuses on ore minerals of gold, zinc, tungsten, molybdenum, and uranium, and their associated hydrothermal alteration halos.

Some key strategic metals and their substitutes that are of significant commercial interest are summarized in Table 4.3-2. New developments in processing remote-sensing imagery and other data will make the search for these materials feasible from Earth orbit. Eventually, as strategic reserves of critical materials are exhausted on Earth, mining from the lunar surface

Table 4.3-2. Key Strategic Metals and Their Substitutes*

Metal	1978 Imports (%)	Main Foreign Supplier	Uses	Substitutes	Recycling (%)	Estimated Domestic Reserves	Expected Increases In Demand (%)
Chrome	92	South Africa Zimbabwe USSR	Alloying agent for jet engines, armor plates for ships and tanks.	No substitutes for industrial hard plating.		8 million tons[a,b]	3.4
			Ball bearings and cutting edges for high-speed tools.	Nickel, cadmium, zinc.			
			Stainless steel alloys for tableware, pots, pans, kitchen sinks, cutlery.				
Cobalt	97	Zaire Zambia	Jet engines and gas turbines	Nickel but loss of effectiveness.	10	585,000 tons[c,d]	3.1
			Magnets				
			Drill bits and cutting tools	Platinum, nickel, barium or strontium ferrite and iron in magnets.			
			Pigment in art, ceramics				
			Cobalt 60 for cancer treatment	Tungsten, molybdenum carbide, ceramics, nickel in machinery			
				Nickel for catalyst			
				Copper, chromium and manganese in paints			
				None in some steel and carbide tools			
Manganese	98	South Africa Australia Gabon Brazil	Strengthening steel and removing impurities	No effective substitutes in its major applications.	Not significant even at substantially higher prices.	Less than 1[e,f]	1.6
			Alloying agent in aircraft components, mining machinery, heavy-duty machinery, rails and ship propellors.				
			Coloring agent for bricks; dryer in paints and varnishes; health protector in germicides; manufacture of dry cell batteries.				
Platinum-group metals	91	South Africa USSR Canada	Chemical catalyst in industry.	Gold, silver and tungsten in electrical industry.	12	300 million troy oz[g,h]	4.0
			Corrosive resistant material in chemical, electrical and glass industries	Gold in dental			
				Tungsten, iron, nickel, vanadium, titanium for catalyst			
			Automobile catalytic converter	Could eliminate as emission control catal.			

[a]70% in Stillwater, Montana. Some in beach sands in California and Oregon.
[b]Prices would have to double or triple.
[c]Mainly in the midwest and far west, about 30% in Idaho.
[d]By-product of copper and nickel ores.
[e]Big deposits in South Dakota.
[f]Monumental mining and waste disposal.
[g]Mostly at Stillwater and Duluth, Minnesota.
[h]Usually by-product of copper.

Source: James A. Miller, Struggle for Survival: Minerals and the West, American African Affairs Association, 1980.

*Caloway, L. and Rensburg, W. C., U.S. Strategic Minerals Options, Resources Policy, Vol 8, Pages 97-108, 1982.

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and other extraterrestrial bodies such as asteroids will become important. Prior to planning revisits to the lunar surface (which will surely occur in the next several decades) significant site survey operations can be conducted from platforms in Earth orbit. A manned Earth-orbiting space station, and the flexibility it would provide in the selective use of multiple sensors, would be a very useful base for such site surveys.

Transient studies of the lunar surface can optimally be made from a space station in Earth orbit because of the absence of intervening atmosphere.

Spectroscopic analyses can be made of transient sites contrasting spectral response at time periods of maximum orbital fluctuation and minimal orbital fluctuation at apogee and perigee. Transients are maximized at perigee and apogee and coincide with moonquakes. Space station observation of transients and associated spectra may provide not only information on the composition of the lunar surface but clues as to earthquake prediction for the Earth. (Earthquake lights--glows on Earth which precede major earthquakes--may possibly be correlatable with lunar transients--an unpublished concept.)

Fraunhofer Line Discrimination is an example of a passive compositional technique for the mapping of the lunar surface that may be implemented from a space station. The Fraunhofer Line Discriminator (FLD), Model Mark II, Perkin-Elmer Corporation, is an airborne photometer that determines and displays real-time values of the luminescence and reflectance of a scene within its field of view. Using the sun to excite this luminescence, the photometer distinguishes solar illumination from the weaker luminescence. Reflected sunlight is coded by narrow Fraunhofer absorption lines, whereas luminescence is not. Narrow band (0.07 μm) optical filters are used to provide in-band and out-of-band light samples from the scene and pure sunlight to a photomultiplier tube which has automatic gain control. The tube detects the energies received from the FLD's Earth-looking telescope and a sky-looking telescope via a diffuse sun target. These energies are sampled alternately through a rotating chopper. Each of the signals received from the telescopes is further split by the chopper to provide both a signal representing the Fraunhofer line and a signal that represents the continuous spectrum on either side of the line. The detector sees four separate signals in sequence at a rate of 40 Hz. The signals are integrated, digitized, and stored for use in a computer. The energy consumption is 400 W; weight is 18 kg (Gabriel and Plascyk, 1981).[9]

Novel spaceborne applications of Fraunhofer Line Discriminator systems have included track pushbroom and scan methods.

Paradoxically, spectral investigation of lunar transients and pioneer Fraunhofer analysis of the ray systems of lunar craters has been done by only one individual and that was in the 1950s: Dr. N. A. Kozyrev of Pulkovo Observatory, Leningrad.

Space station objectives in lunar exploration include detection of volcanic vents which may host hydrothermal products and proto-life forms. These resources may be a source of water on the moon.

At the present time, lunar resources are inadequately known. Possible ore concentrations in g/kg may be as follows:

Aluminum	194	from anorthosite
Iron	92	
Titanium	79	from ilmenite
Oxygen	79	
Native iron	5	
Chromium	?	
Platinum	?	
Copper	?	
Basalt	(unlimited)	
Clay	?	
Sulfides	?	
Ice	?	

These levels are great enough to be of commercial interest.

[9]Gabriel, F. C. and Plascyk, J. A., Functional Design of the Perkin-Elmer Fraunhofer Line Discriminator, Lunar Plan. Inst. Report 81-03, Pages 12-13, 1981.

Orbiting satellites using beam technologies can offer high-resolution analyses of possible ore deposits in conjunction with onboard spectral analysis systems. Eventually, landers using nuclear spectroscopy methods and appropriate robotics will yield volume analyses in meaningful geological targets (breached central mountains, floors of eternally shadowed craters, etc.).

In addition to lunar mining, considerable interest has been generated in asteroidal recovery for precious metals (O'Leary et al., 1979. Pages 173-189).[10]

Trivial delta Vs would be required to guide minable asteroids into cis-lunar orbits. Processing asteroids at a lunar base would then become possible.

Probes to nearby asteroids could be launched from a space station using artificial intelligence sensors to determine economic potential of the body. Table 4.3-3 illustrates the logic. Similar tables can be constructed for the assessment of lunar resources.

The sensor would determine the metallic nature of the asteroid by gravimetry (density greater than eight). In general, if the emissivity of a reflected energy beam or thermite arc is below 0.35, gold or silver may be present. If the neutron capture cross section is above 5, precious or strategic metals may be present. If major spectral lines are seen in the beam or thermite arc, platinum, gold, or silver may exist.

Remote sensing operations from a manned space station are integral to planning for a lunar base. A possible scenario might be predicated upon a lunar polar base where the continuous sunlight at the lunar poles could be used for power generation for resource processing and transformation to laser microwave energy for use in cis-Earth.

A lunar base would permit export of resources to cis-Earth space at 1/20 the cost of sending resources there from the Earth.

[10] O'Leary, B. et al, <u>Retrieval of Asteroidal Materials</u>, Space Resources and Space Settlements, NASA SP-428, Pages 173-189, 1977.

Table 4.3-3. Smart Sensor Exploration Parameters for Metallic Asteroids

Element of Interest	Spectral Emissivity		Thermal Neutron Capture Cross-Section	Diagnostic Spectral Emission Lines (arc)	
	Solid	Melt			
Matrix					
Fe	0.35	0.37	2.62	3719.935 2382.039	(i)* (ii)**
Ni	0.36	0.37	4.6	3414.705 2287.084	(i)* (ii)**
Precious/Strategic Metals					
Pt	0.30	0.38	8.8	3064.712	(i)*
Pd	0.33	0.37	8.0	3464.580 2296.530	(i)* (ii)**
Rh	0.24	0.30	149.0	3434.893	(i)*
Au	0.14	0.22	98.8	2427.95	(i)*
Ag	0.07	0.07	63.0	3280.683 2437.791	(i)* (ii)**
Co	0.36	0.37	38.0	3453.505 2286.156	(i)* (ii)**

(i)* and (ii)** refer to valence levels. Spectral emissivity is under unoxidized conditions at 0.65 μm.

Stockpiling of metals (aluminum, AISI 4130 hull steel, etc.) at the polar lunar base is considered essential to buildup and modularization of the future space station systems of the 21st century.

4.3.2 The Impact of Remote Sensing on a Space Station

Space and weight requirements for sensor systems are assumed to be minimal inasmuch as sensor sets will probably be in modularized platforms, some with separate orbits from the space station.

Each sensor platform can be assumed to have solar or battery power pack units of a modular design for replacement from a space station, as required.

Typical instrumental combinations might involve Landsat, SAR, and Thematic Mapper for resources exploration and management. A large number of other sensor combinations from geophysical and atmospheric sensing platforms (Seasat, Magsat, Stereosat, Lageos HCMM, GOES, etc.) are likely.

Power and weight requirements for a lunar orbiter conceivably launched from a space station are summarized in Table 4.3-4 as an example of an instrument set packaged for a specific mission. Table 4.3-5 summarizes the suggested payload for a relay platform to operate in conjunction with the lunar orbiter.

Power from a lunar orbiter will be required for active beam technology compositional mapping.

For the launch of lunar probes (both orbiting and landers) LEO to lunar orbit, delta Vs of 3.9 km/sec will be required.

4.3.3 The Role of Manned Systems in Remote Sensing

Eventually, artificial intelligence methods can be expected to supplant man in the detection of change or in the recognition of anomalies from space. However, man will be needed to assess rates of change and the significance of anomalies. He will be needed to perform additional measurements of short-term phenomena: spectroscopy of lunar transients, additional sensors to define a hazard, side look of volcanic plumes, etc. Man, if an experienced observer, will have intuition concerning observables.

Man will be needed for special study investigations by organizations with proprietary targets.

Man in space, however, is a poor observer of phenomena over protracted time periods. The short-term and special target observations of terrestrial phenomena will probably represent less than 5% of time devoted to Earth observation activities. Over 95% will probably be by automated sensors. In the remaining 5%, however, onboard optics will be required for man.

Table 4.3-4. Model Payload, Lunar Polar Orbiter (ESA, 1979)

Experiment	Measurement	Scientific Objectives	Weight (kg)	Power (W)	Data Rate (kbps)
*1. X-ray Spectrometer	Measures the K-lines of Mg, Al and Si.	Determine the major element chemistry of the lunar surface.	7	10	0.3
*2. Gamma ray Spectrometer	Measures the gamma rays produced in about the upper 30 cm of the moon.	Determine K, Th, U, O, My, Si, Ca, Ti and Fe in the lunar surface rocks.	16	5	2
*3. Multi-spectral stereo imaging system	Produces multi-spectral images.	Determines surface morphology and gives information on composition (mineralogy)	4.5	5	approx. 100 Mb per orbit
*4. Reflectance Spectrometer	Measures the reflectance spectrum in the range 0.3 to 2.5 μm.	Determines mineralogic composition.	6.5	9	
*5. Altimeter	Altitude measurements	Topographic maps. Shape of the moon. Non-hydrostatic equilibrium. Upper crust structure.	7	20	0.165
*6. Alpha-particle Detector	Alpha-particle time and space distribution	Locate sources of transient release of gas--moonquakes?	1.8	1	0.1
*7. Magnetometer	Magnetic field 0.1 → 1000 γ to 1 Hz	Remnant lunar magnetism >10 km scale range; conductivity profile.	2	2.5	0.1
*8. Tracking Experiment	Doppler observable from earth: directly or via the relay.	From analysis of orbital perturbations: gravity field (especially far-side); dens. models; lithospheric struct.	-	-	-

*indicates core payload

Table 4.3-4. Model Payload, Lunar Polar Orbiter (ESA, 1979) (Cont.)

Experiment	Measurement	Scientific Objectives	Weight (kg)	Power (W)	Data Rate (kbps)
9. Electron Reflection Detector	Reflected flux of solar electrons	Surface Magnitude of lunar field	8	4	1.5
10. Infrared Telescope	Black body radiation from the surface	Determination of surface temperature	5	1	0.3
11. Microwave Detector	Black body radiation from small depths in the regolith	With measurement of (10) the determination of the temperature gradient & heat flow : global mapping	13	12	0.2
12. Dust Detector	Velocity and mass of dust particles above the lunar surface	The study of interplanetary dust & dust levitating from the lunar surface	5	3	0.01
13. Mass Specrometer	Measurement of gases in transient atmosphere and alpha particles	Study of generation & loss processes of the lunar atmosphere	7.5	3.5	1

*Indicates core payload

Table 4.3-5. Model Payload, Relay Platform for Lunar Polar Orbiter (ESA, 1979)

Experiment	Measurement	Scientific Objectives	Weight (kg)	Power (W)	Data Rate (kbps)
*1. Tracking Experiment	Doppler observable from Earth. Link to the Orbiter over the far side	Complementary to 8 (for the far side). Mean moment of inertia (existence of a core). Non-hydrostatic equilibrium	-	-	-
2. Radiowave Receiver	Electric and magnetic fields	Physics of heliosphere, baseline for ISPM, collisionless wake, Terrestrial Kilometric Radiation	6	5	TBD
3. Plasma Analyser	Solar wind electrons & protons	As above	5	5	TBD
4. Cosmic Ray Detector	Cosmic energy & charge spectrum	Baseline monitoring for ISPM. Modulation and galactic propagation structures.	7.4	7	0.15
*5. Magnetometer	Magnetic field up to 10 Hz	Conductivity of the Moon and baseline for ISPM	2	2.4	0.1
		TOTALS	101.7	95.4	

*Indicates core payload

For both Earth and lunar observations, the dominant role of man will be operational. His functions will include:

- Limited active sensor operations for Earth studies
- Major active sensor operations for lunar studies
- Lunar probe launch and guidance
- Cis-Earth space station interaction
- Maintenance of sensors
- Repair of sensors
- Deployment of sensor platforms
- Orbital adjustments for sensor optimization
- Backup for directional look angles of sensors

Artificial intelligence techniques have already reached an impressive level of sophistication, as indicated in NASA Conference Publication 2255 based on a 1980 NASA Summer Workshop at the University of Santa Clara.

Space station planning has already involved this technology; it is particularly applicable to both Earth and space sensing for detecting anomalies and change rates.

In summary, artificial intelligence will play an important role in most Earth and lunar sensing, but man will be required for all remote sensing in a space station in terms of:

a. Teaching the machines
b. Short-term phenomena requiring immediate actions
c. Optical viewing of specific targets under special conditions for commercial or proprietary purposes
d. Maintaining and repairing sensors.

The general characteristics of remote sensing missions are listed in Table 4.3-6.

Table 4.3-6. Remote Sensing Missions

- High-inclination, low-altitude orbit
- Long-duration (continuous) missions
- Unmanned for routine mapping or periodic, large-scale surveys of slowly changing phenomena (i.e., minerals, forestation, crops, weather)
- Manned for detection and observation of unknown phenomena, transient conditions, and small-scale characteristics (i.e., toxic spills, disaster warning, search and rescue, event correlation)
- Low power for passive sensing
- High power for radar sensing
- Earth-oriented, wide field of view
- Pointing and control, precision reference
- High data rate, wide-band data collection and storage (tape)
- Communications link to TDRS
- Imagery and ground voice link for manned missions
- External mounting provisions
- Internal, pressurized mounting for manned access sensors
- Provisions for EVA or robotic access to sensor assemblies and hard-data cassettes for removal and replacement
- Access for checkout and repair
- Provisions for protection of proprietary data

4.4 EMERGING INTERESTS

The search for candidate new commercial mission sponsors has led to the list of potential users shown in Table 4.4-1. In developing these potential users, Booz, Allen & Hamilton has been very effective in acting as an objective, "third party" interface with some of the candidate mission sponsors and in providing "seed concepts" to stimulate creative thinking for new product opportunities. Their efforts, particularly the investigative work done by Dr. Myron Weinberg, has led to the identification of potential products in several candidate areas.

Table 4.4-1. Potential Commercial Users Identified by the McDonnell Douglas/Booz, Allen & Hamilton Team

Staley		AT&T
Eaton		Monsanto
Tucker Anthony		Eli Lilly
DuPont	Fluor	Fluor
Bethlehem Steel		IBM
Microgravity Research Assoc.		Eastman Kodak
John Deere		Union Carbide
GTI		Baxter Travenol
Celanese		Allegheny International
Perkin-Elmer		Johnson Matthey
McDonnell Douglas		Nitinol Products
Hoffman LaRoche		Calcitek
GEOSAT Companies		Chemical Manufacturers Assoc.
Schering Plough		Venture Capital Groups
SmithKline Beckman		US Time
Allied Corporation		Special Metals Corporation

From contacts made to date (Appendix 3.0), a lengthy list of possible space products and processes has been identified as summarized in Table 4.4-2.

In many cases, there is interest from these potential users in doing materials and processes research in orbit but a reluctance to speculate about the potential for large-scale production of materials and products in space until essential research is completed. This condition could continue until a permanent facility is established in space in which to conduct the research needed to move these products out of the idea phase and into development and pilot production. In the meantime, there are valuable research objectives that could be pursued in Shuttle/Spacelab if adequate interest could be stimulated among the candidate commercial sponsors.

One such area of high interest, with a major market potential, is the production of ultrapure iridium crucibles, discussed in Section 3.1.1. Similar methods can be used to produce improved-quality materials for electronics and sensors, including silicon, gallium arsenide, and indium antimonide. These improvements could generate a new market for unique and ultrapure elements and compounds exceeding $1 billion in the 1990s.

Table 4.4-2. Candidate Space Processes and Products

Processes	Products
Electrophoresis	Pharmaceuticals
Melting/Refreezing	Diffraction Gratings
Containerless Processing	Silicon Ribbon
Homogeneous Mixing	Crystals/Diffractors
Unidirectional Processes	Passive Membranes
Hot/Cold Processes	Biologically Active Membranes
Ultrarapid Cooling	Catalysts
Beam Etching	Composites
Vacuum Metalizing	Emulsion Polymers in Plastic Filaments
Zone Refreezing	Gallium Arsenide Crystals
Fermentation	Iridium Crucibles
(Proprietary)	High Strength Polyethelene
	Ultra-catalysis
	Clad Metals

The potential benefits of candidate commercial processing and manufacturing missions are so vast that any future space station concept must be responsive to the needs of this mission group. Table 4.4-3 summarizes these key needs, and Figure 4.4-1 illustrates a manned space laboratory for conducting materials and processes research and development and pilot production in space. Orbit location is not critical to this group of missions, but low-cost readily available access to space is. Electrical power is needed in large quantities (15-kW range) and manned participation is essential, especially during the R&D phase. Mission duration is important in that each day in orbit provides more R&D opportunity without a substantial increase in transportation cost.

Descriptions of five potential near-term commercial mission opportunties are presented in Appendix 2.0.

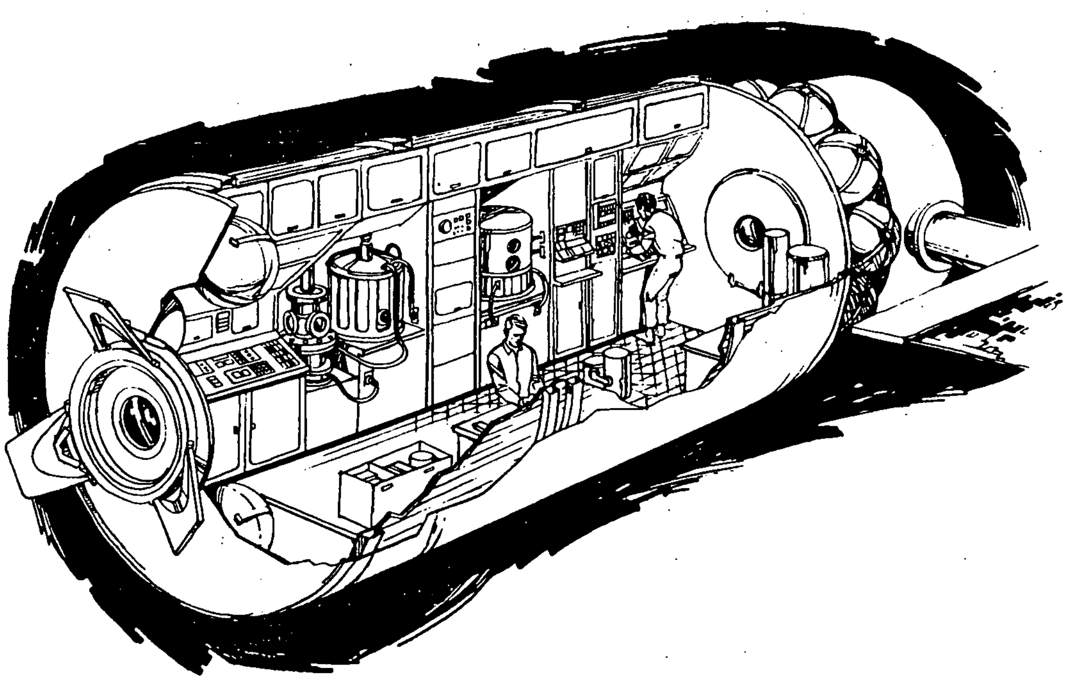
Table 4.4-3. Key Requirements for Materials Processing and Manufacturing Missions

- Any orbit location with low-cost, frequent access
- Micro-g environment
- Short-duration missions (days) for R&D
- Long duration (months, years) for production
- Very high power and thermal (25-kW range)
- Manned access required for R&D; preferred for production
- Unmanned (or intermittent manned access may be acceptable for production)
- Large pressurized volume with vacuum accessible
- Isolated, controlled atmosphere (for biological and medical missions)
- Multipurpose laboratory equipment
- Low data rate; voice ground link; intermittent video (secure links)
- Provisions for materials resupply and product return
- Provisions for protection of proprietary data and products

FIGURE 4.4-1

VGB280

MANUFACTURING IN SPACE



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Section 5

COMMERCIAL OPPORTUNITIES FOR USER SUPPORT SERVICES

As private interest in the commercial utilization of space for providing specific products and services grows during the coming decades, corollary opportunities will also develop for the marketing of support services to these prime users. Typical support service opportunities will include **Launch and Orbital Transportation Services**, **Operational Support Services**, and **Development and Verification Services**.

5.1 LAUNCH AND ORBITAL TRANSPORTATION

The transportation of payloads and cargo to space has already become a commercial activity and is a rapidly expanding segment of the aerospace industry. Table 5.1-1 lists existing commercial launch vehicles and upper stages and candidate commercial ventures for the near future in the field of launch and orbital transportation. The transition from NASA sponsorship to private investment and operation is indicative of the advancing maturity of the industry and of the private sector's confidence in the commercial opportunities of space. Foreign space transportation technology is also advancing rapidly and poses a serious challenge to U.S. industry in the competitive marketplace. To remain competitive, the U.S. industry must continue to provide reliable, low-cost launch services, on schedule, and suited to the customer's functional and performance needs. The McDonnell Douglas Payload Assist Module (PAM) is an example of a successful, privately financed commercial venture, which offers reliable, fixed-price launch services from LEO to geosynchronous transfer orbit. The steadily rising demand for this product is shown in Figure 5.1-1. The projected market for this product is expected to be in the range of 15-20 per year as we progress into the 1990s.

Table 5.1-1

COMMERCIAL SPACE TRANSPORTATION

COMMERCIAL ACTIVITY	SYSTEM	COMPANY	STATUS
Expendable Launch Vehicle	Delta Model 3914	McDonnell Douglas	Operational
Expendable Upper Stage Vehicle	Payload Assist Module (PAM)	McDonnell Douglas	Operational
Launch Vehicle Leasing	Shuttle Orbiter 5	Space Transportation Co.; Prudential Insurance	Proposed
Expendable Launch Vehicle	Titan 34D	Space Transportation Co.; Martin Marietta	Memo of Intent
Expendable Launch Vehicle	Conestoga	Space Services, Inc. (SSI)	Flight Tested (suborbital)
Orbital Platform	MESA Satellite	Boeing Company	Developed.
Orbital Platform	Leasecraft	Fairchild Corp.	Planned.
Expendable Launch Vehicle	Atlas Centaur	Space Services, Inc. (SSI)	Study
Expendable Launch Vehicle	Ariane	Arianespace	Operational

FIGURE 5.1-1

PAM APPLICATION FOR COMMERCIAL AND FOREIGN MISSIONS

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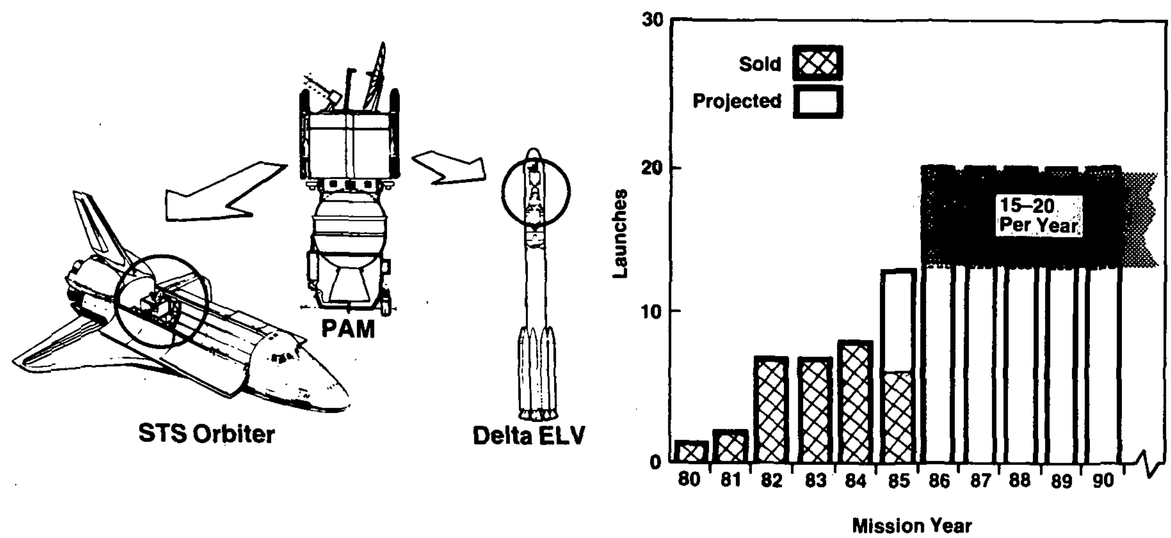

5.1.1 A Reusable Orbital Transfer Vehicle (ROTV)

As commercialization of space expands, the demand for higher performance and more efficient, lower cost launch services is expected to increase. At present, the U.S. shuttle is the only reusable launch vehicle in operation. The currently available upper stages, and those in development, are basically expendable stages, although the orbital support equipment used in the shuttle cargo bay is reusable. Development of a cryogenic, fully reusable orbital transfer vehicle (ROTV), promises both performance and economy improvements over current and planned expendable stages. For maximum economy, this system would be placed in low Earth orbit and remain in orbit to be fueled, serviced, and launched from a manned space station. Based on current cost and traffic estimates, this system appears economically viable and could be considered as a candidate for commercial development and operation. Figure 5.1-2 is a projected traffic model for geosynchronous missions in the 1990s that would be candidate payloads for a reusable upper stage. An ROTV sized for a 4000 kg payload, and equipped for multiple payload delivery up to this total, would offer major operating cost advantages in comparison with the projected inventory of expendable stage alternatives. By combining delivery missions

FIGURE 5.1-2

VGB285

SPACE STATION DEDICATED SATELLITE TRAFFIC MODEL

CODE	NAME	#LAUNCHES PER YEAR 90	91	92	93	94	95	96	97	98	99	10 YR TOTAL 00	INC DEG	ALT KM	MASS KG
XAS012	SIMULT ASTRO EXP	1	0	0	0	0	0	0	0	0	0	1	0	GEO	2000
XAS013	FAR UV SPECT EXP	1	0	0	0	0	0	0	0	0	0	1	0	GEO	1000
XCM001	INTELSAT VI	2	1	2	2	0	0	0	0	0	0	7	0	GEO	2004
XCM002	INTELSAT VII	0	0	0	0	1	2	3	2	0	0	8	0	GEO	3636
XCM004	TEL	0	0	0	0	1	0	0	0	0	0	1	0	GEO	702
XCM005	WESTAR	0	0	2	1	0	0	0	0	0	0	3	0	GEO	626
XCM006	TDRS/ADV WESTAR	0	1	0	1	1	1	1	0	0	0	5	0	GEO	2273
XCM007	SATCOM	0	0	1	1	1	1	0	0	0	0	4	0	GEO	895
XCM008	SBS	0	1	0	0	1	1	1	0	0	0	4	0	GEO	550
XCM009	GALAXY	0	0	1	1	0	1	0	0	0	0	3	0	GEO	632
XCM010	SYNCOM	0	0	0	0	0	2	1	2	0	0	5	0	GEO	1314
XCM011	GSTAR	0	0	0	0	0	1	1	1	0	0	3	0	GEO	702
XCM013	STC	0	0	0	2	2	2	0	0	0	0	6	0	GEO	702
XCM014	DBS	2	0	0	0	0	2	2	2	0	0	8	0	GEO	1136
XCM016	DATA TRANS	1	0	0	1	0	1	0	1	0	0	4	0	GEO	636
XCM017	BANKING	0	0	1	0	0	1	0	0	0	0	2	0	GEO	636
XCM018	MAIL	0	1	0	1	0	1	0	0	0	0	3	0	GEO	636
XCM019	SATCOL	0	0	0	1	1	0	1	0	0	0	3	0	GEO	715
XCM021	TELESAT	1	0	2	0	1	0	0	1	0	0	5	0	GEO	702
XCM022	CHICOMSAT	1	0	0	0	1	1	0	1	0	0	4	0	GEO	702
XCM023	PALAPA	0	1	0	1	0	0	1	0	0	0	3	0	GEO	632
XCM024	MISC	0	1	1	0	1	1	0	0	0	0	4	0	GEO	702
XCM025	NATO	0	0	0	0	0	1	1	0	0	0	2	0	GEO	432
XCM026	TRACK/DATA ACQUISIT	0	0	1	0	0	0	0	0	0	0	1	0	GEO	3000
XEE004	GEO OP/ENV SAT	0	0	1	0	0	0	0	1	0	0	2	0	GEO	874
XEP001	GEOS	2	0	0	0	2	0	0	2	0	0	6	0	GEO	400
XXX002	INSAT	0	1	0	0	1	0	0	0	0	0	2	0	GEO	591
	Total Missions:	11	7	12	12	14	19	12	13	0	0	100			117798

where possible, a total of 39 ROTV flights from LEO to GEO would be needed to accommodate this 100-mission profile, as shown in Figure 5.1-3. Note that this mission model represents a conservative estimate of only 13 missions per year; a number that could easily double if more optimistic traffic projections prove correct. The approximate total cost to accommodate this 100-mission model with a reusable two-stage OTV is $2.4 billion, which compares to approximately $4.5 billion, using a mixed fleet of expendable upper stages operated from the shuttle. In both cases the development non-recurring costs have been omitted. The resulting cost differential is largely due to the reduction in shuttle transportation costs that occurs because only payloads and propellant need be transferred from Earth to LEO. By scavenging residual propellant from the external tank and/or topping off each shuttle flight with cryogenics to maximum lift capacity, a further decrease in launch transportation costs can be achieved. The differential savings should easily pay for development costs, and additional operations costs for the more complex system, and provide a reasonable profit.

FIGURE 5.1-3

REUSABLE ORBITAL TRANSFER VEHICLE (ROTV) FLIGHT SCHEDULE

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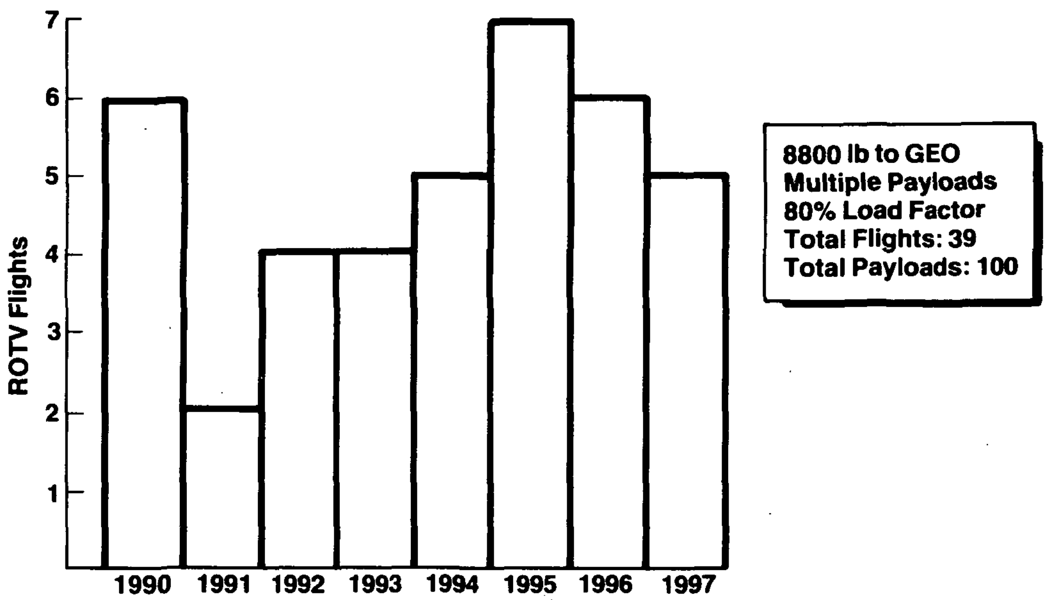
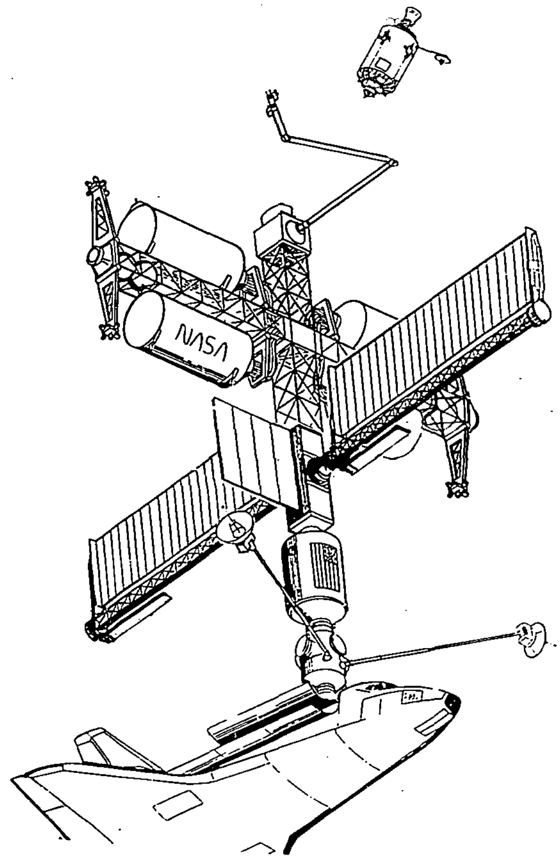


The operation of a reusable OTV from a low Earth orbit base would be a complex activity requiring propellant transfer and storage, rendezvous and docking, payload/ROTV mating and checkout and, finally, the launch operation itself. What would such a system consist of ? Figure 5.1-4 illustrates one concept which is a small manned space station built in conjunction with a propellant storage depot and an ROTV staging base. The complexity of such a system is apparent, but it must be measured against the market potential exceeding $2.4 billion over 8 years. More importantly, the availability of a space station like this in low Earth orbit, and at a 28-degree inclination to accommodate GEO transfer, would be well suited to a variety of high-value missions serving scientific and technological needs as well as dozens of other commercial objectives. The resulting investment per mission category would be relatively low.

VGB382

FIGURE 5.1-4

A MANNED SPACE STATION SERVING AS AN ORBITAL TRANSPORTATION STAGING BASE



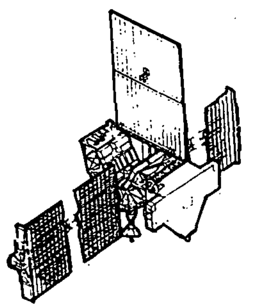
5.1.2 The Space Platform

At present, U.S. assets in space consist solely of dedicated mission satellites. Although some commercial satellites (e.g., communications satellites) are shared by multiple users, none provide common support services to multiple payloads with the ability to exchange payloads during orbital operation. The demand for such a multipurpose satellite, or space platform, is growing and offers the advantage of reduced cost to users through sharing of central power, control, thermal, communications, orientation, and other services. Figure 5.1-5 shows features of two such candidate systems. The first is a very low-cost, limited-capability option based on use of PAM orbital support equipment--principally the cradle structure and avionics. The second is a more versatile design developed by MDAC under contract to Marshall Space Flight Center. For orbital missions that are satisfied with an unmanned, unpressurized environment, the space platforms can be an attractive alternative to developing a mission-unique satellite. For the entrepreneur, the manned platform is an opportunity to develop and operate an orbital transportation service for multiple customers. "Leasecraft," being considered for commercial development by the Fairchild

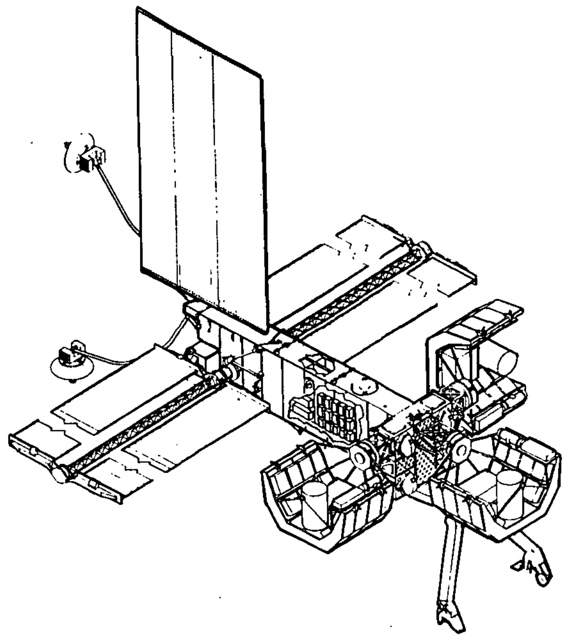
FIGURE 5.1-5

VGB287

SPACE PLATFORM DESIGN CONCEPTS



a 4-kW Concept Developed by MDAC Based on Use of PAM Support Structure and Avionics System



11.5-kW Concept Developed by MDAC for MSFC

Space Company[1], is another example of such a product. Based on technology and modular concepts developed on NASA's Multimission Modular Spacecraft (MMS) program, Leasecraft offers nearly 5 kW of regulated power, plus stabilization, data, communications, and other services to prospective users. As in the launch vehicle area, foreign competition for the space platform business is emerging. A European consortium, lead by MBB/ERNO and sponsored by ESA, is developing EURECA, a small, reusable platform for multiple payload use.

In the present study, a number of potential individual payloads were identified as candidates for space platform missions. Many of these missions are intended to be operated in conjunction with, and some in close proximity with, a manned space station. As a candidate commercial enterprise or NASA program, the building and leasing of multipurpose unmanned space platforms appears to have a sizeable market in the 1990s; perhaps exceeding $100M/year.

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(1)Cohen, Morton, H., Leasecraft - An Innovative Space Initiative, Signal, February 1983, pg. 56.

5.2 SATELLITE SERVICING AND OPERATIONAL SUPPORT MISSIONS

As the quality and value of our space assets grow, there will be increasing needs for logistics support and orbital maintenance and repair services. At present, several high-value satellites are inoperable or malfunctioning and are candidates for such service; still others are planned which will require periodic servicing and support as part of normal operations. Present intent is to perform these tasks from the shuttle as NASA operations using NASA-provided support and servicing equipments. As these operations become routine, however, possibilities can be envisioned for transition to commercialization as with any other sophisticated servicing activity. The operations will probably involve the use of a Teleoperator Maneuvering System (TMS) for retrieving and transporting payloads and supplies between orbit locations and, in a high-demand environment, the TMS itself becomes a candidate commercial product. As with the ROTV, a permanent space station is key to providing such services on a routine, economical basis.

From the list of candidate servicing support and requirements in Table 5.2-1 it is apparent that these activities will require extensive investment in servicing and support equipment and involve considerable training and specialized gear for each specific mission. Since these types of missions are yet to be conducted, and will depend on specific mission needs as they arise, the market potential and benefits to the mission users are difficult to project at this time. However, if the dollar value of a restored satellite is assessed at only $100 million, and two or three of these are repaired each year, it is easy to reach a market value of $2 to 3 billion for the 1990s.

The kinds of functions listed in Table 5.2-1 are only feasible at present with manned participation. For specific cases, remotely controlled operations may prove feasible, but the ability to respond to any mission need and to resolve real-time problem situations with efficiency will require manual operations in orbit. Early missions in satellite repair will use shuttle as the base of operations. This will certainly be feasible in the long term for many servicing and repair operations involving pre-planned, short-duration EVA task activities. For more complex operations involving extensive disassembly, extensive repair/replacement tasks, calibration, checkout, alignment, cleaning, and other extended operations, accessibility to a manned station will be

Table 5.2-1

OPERATIONAL REQUIREMENTS FOR

SATELLITE SERVICING AND OPERATIONAL SUPPORT MISSIONS

- Access to all payload orbits
- Teleoperator Maneuvering System (TMS)
- Rendezvous and docking provisions (automatic and manned)
- Remote-controlled manipulators
- EVA access
- Grapple and external attachment and positioning provisions
- Gas, fluid, and propellant storage and transfer provisions
- Diagnostic equipment
- Assembly/disassembly, alignment and calibration tools and fixtures
- External lighting
- Solar shield for temperature control
- Extensive crew support
- Short-duration, infrequent missions (hours, days, weeks)
- Voice and video links
- Low data rate
- Low power and thermal
- Parts replacement and repair (internal, external)
- Pressurized laboratory, general-purpose instruments and tools; cleaning provisions
- Provisions for retrieval and stowage for de-orbit
- May require pressurized hanger (requirement TBD)

essential. With many high-value satellites in low-inclination orbits that are accessible with a TMS, and a reusable OTV to retrieve geosynchronous and high-inclination satellites, the feasibility of conducting a large number of satellite servicing and repair missions on a manned space station is enhanced. Fortunately, these types of activities are fully compatible with other ROTV missions and transportation operations to be conducted on a space station.

5.3 DEVELOPMENT AND VERIFICATION SERVICES

The accessibility of a manned space station served by the shuttle opens up new possibilities for in-orbit testing, evaluation, assembly, calibration, alignment, checkout, and other forms of development and product verification activities. Any new space project or product is a candidate for these services. Environmental testing of new government and commercial space products is already a major aerospace industry, and a space-based counterpart is certainly a possible commercial opportunity for the future. The advantage of this form of testing is exposure to the real space environment under controlled operating conditions before committing to final production or final orbit placement. A related service is the measurement and collection of environmental data needed for design and calibration of new space products. Examples of interest are:

- Sensor and detector testing against realistic background.
- Fluid systems (including cryogenic) testing in weightlessness.
- Thermal properties measurements vs. ground simulation.
- Dynamic properties testing in weightlessness vs. ground simulation.
- Assembly, deployment, and alignment of antennas and large satellite structures.
- Checkout and verification of satellites prior to final placement in orbit.
- Testing of antenna patterns and electromagnetic field properties in the realistic environment.

This last item is of special interest to satellite communications developers. Ford Aerospace and Communications Co., for example, has expressed interest in orbital testing of satellite antenna patterns that cannot be accurately predicted or tested on the ground. Errors in pattern and signal strength can result in such substantial loss in revenue that testing in space may be a cost-effective alternative to less accurate on-ground testing and prediction.

For all of the cases noted above, the alternative is to accept the risk that ground-based analysis, simulation, and testing will be adequate. As the orbital systems become more complex and more expensive, the risk for in-space testing and verification will increase.

Table 5.3-1 lists some of the major requirements and functions of this class of missions. For most envisaged needs, manned participation is again required and the operations involved are compatible with satellite servicing and ROTV activities. This type of mission is attractive from the standpoint that timing is generally not critical, activity duration is short, and most missions are insensitive to orbit location. These features simplify mission planning and scheduling.

Table 5.3-1

DEVELOPMENT AND VERIFICATION SERVICES MISSIONS

- Any orbit location with low cost, frequent access (most missions). Some missions may require special background, radiation, or magnetic conditions.
- Short-duration, infrequent missions (hours, days). Longer duration if large assembly, calibration, or problem resolution is required (weeks).
- Manned access (hands-on internal; EVA external).
- Pressurized volume (some missions).
- External mounting (some missions).
- Very low average power; some peaks to kW range.
- Wide-band data collection and storage (short duration).
- Low-data-rate command and voice link; intermittent video.
- Micro-gravity environment.
- Laboratory instrumentation and tools.
- External manipulator and servicing devices.
- High pressure gas, fluid, and propellant servicing.
- May require cryogenic servicing.

As with satellite servicing missions, the commercial market value of this type of mission activity has not been fully assessed. Transportation costs from ground to LEO will be a major factor in determining if this type of service is to be used. The most likely mission candidates are new systems intended for remote orbit locations where in-place servicing or modification is impractical and pre-placement verification is a cost-effective investment. A few such missions each year could equate to a total market value of $500 million to $1 billion in the 1990s.

Section 6
SPACE COMMERCIALIZATION - ISSUES AND OPPORTUNITIES

Future growth in the commercial utilization of space depends directly upon effectively integrating the time-phased requirements of potential commercial users with the time-phased development of the space station capabilities. The development of integrated mission scenarios must be predicated upon an understanding of the economic and technical issues that in turn drive the commercial development of products and services. To this end an understanding of the way in which potential users establish the economic and technical validity of their commercial objectives is required. In developing future mission scenarios, program planners must consider the sensitivity of user requirements to space station design characteristics and have an awareness of those user requirements which, should they not be met, will significantly impact the commercial utilization of the space station.

With this information, integrated mission scenarios can be developed and appropriate actions can be taken to enhance the probability of the space station utilization by commercial entities. A typical example of how the user assessment of the economic and technical validity of a product or service leads to the development of a detailed scenario for future missions can be drawn from the experience of McDonnell Douglas Astronautics Company and Johnson and Johnson in the ongoing Electrophoresis Operations in Space (EOS) program being pursued under a NASA-MDAC Joint Endeavor Agreement.

The initial market analysis conducted by MDAC prior to embarking on this program investigated products amenable to electrophoresis (hormones, enzymes, cells, and proteins); defined the benefits and needs of each, and sought to identify those products with a uniqueness that could make EOS a favorable method of production.

As described earlier in this report, these analyses led to the identification of 12 products that could offer significant social and economic benefits to the rest of the world. Economic analysis suggested that the potential market for products produced by this manufacturing technique could be in the $ billion/yr range. The 10-year development plan to penetrate these market areas involves establishing the technical validity of the approach through process proof of principle (initiated during the flight of STS-4 and continuing on STS-6, -7, -8, -12, and -16), pharmaceutical product evaluation, and demonstration of a production prototype system.

Once the basic proof of principle has been established, the development schedule for specific pharmaceutical products will vary, depending on the product properties, use, prior state of development, etc. A typical schedule, however, appears to be about 5 years. This time allows for market research, product development, clinical programs, and production verification.

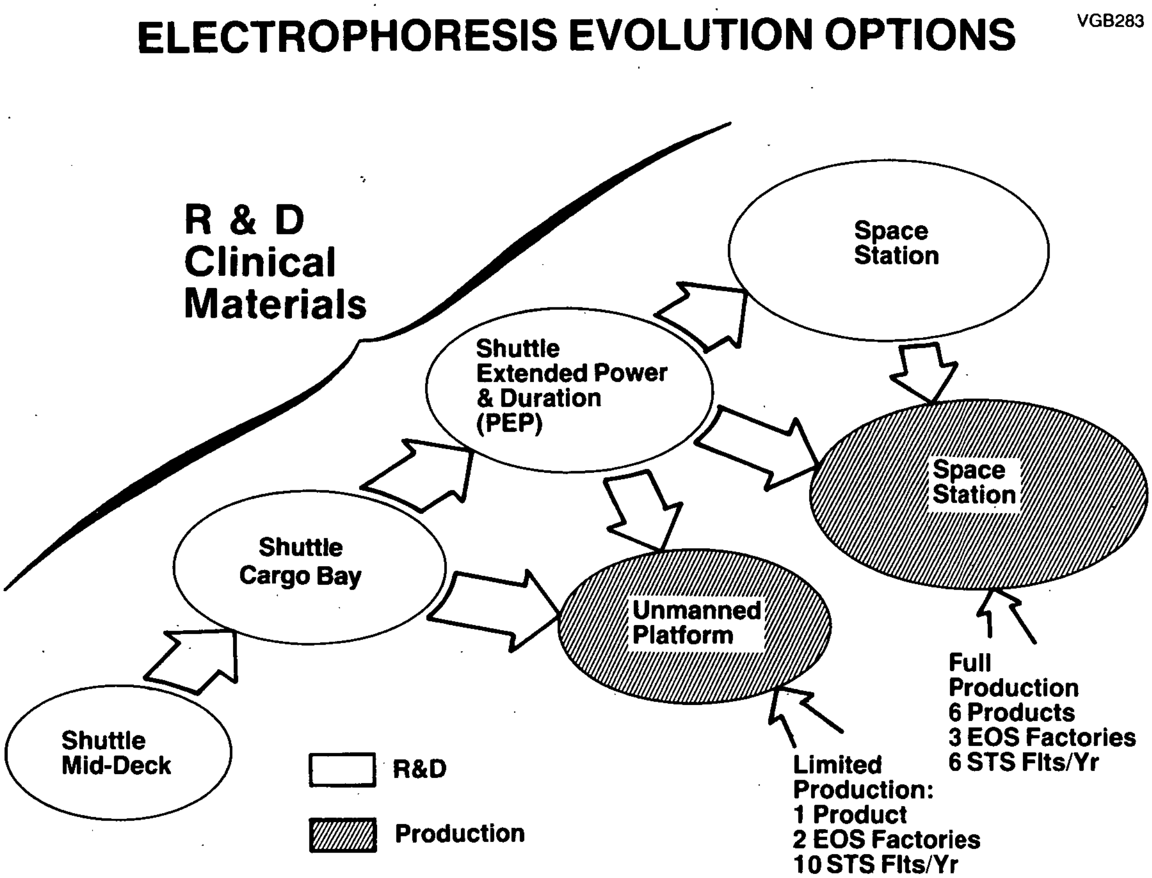
In this EOS example, the integrated mission scenario includes initial phases utilizing the orbiter mid-deck, followed by expanded operations in the orbiter bay, and eventually by longer-duration production processing facilities supported by man-tended free-flying platforms or by permanently manned space stations (Figure 6-1).

It is obvious that user investment in the research and development process and in the production plant development depends heavily upon the time phasing of the availability of future space facilities. This becomes a critical factor for the potential user in establishing the economic viability of any given commercial development program.

As ideas are advanced and as concepts are developed for potential commercial applications, NASA must be prepared to assess the validity of the claims of specific commercial uses/users and for those of highest potential, to be prepared to encourage financially or technically the development of the application. This includes the integration of potential mission scenarios into a master traffic model and schedule for the utilization of advanced space systems, including platforms, space stations, orbital transfer vehicles, and the Space Transportation System itself.

FIGURE 6-1

ELECTROPHORESIS EVOLUTION OPTIONS



With the exception of some remote-sensing missions, all of the candidate commercial opportunities listed in the previous sections can be accommodated in or near a manned space station placed at a 28-degree inclination in low Earth orbit. An altitude of about 220 to 235 nmi is a good compromise between launch vehicle performance and orbital lifetime.

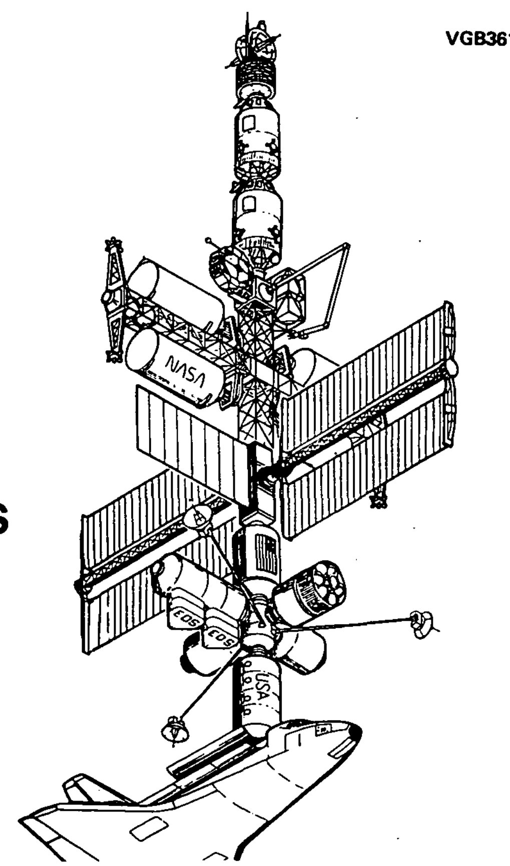
A rough estimate of the total 10-year market potential from all candidate commercial missions is:

Reusable Transfer Vehicles	$ 2.5B
Space Platforms	$ 1B
Satellite Servicing and Support	$ 2-3B
Development & Verification Services	$ 0.5B
Remote Sensing	$ 0.5-1B
Electrophoresis/Pharmaceuticals	$20-40B
New Materials Processes & Products	$ 1-10B
Approximate Total	$40 Billion

The space station concept illustrated in Figure 6-2, which is configured to support propellant storage and ROTV and payload servicing and staging, also contains most of the elements to support the other classes of commercial missions. Additional power, crew, and laboratory/production facilities would be required. In assembly sequence, the basic manned station with laboratories for materials and processes research and development would be done first; this is the most urgent need if we are to establish a multiproduct, multitechnology industry in space. This would be followed by production facilities, with pharmaceuticals representing the first product line. In parallel, the development of the cryogenic reusable transfer vehicle and the facilities for propellant transfer and storage in-orbit would be developed. These would be transported in the manned station via shuttle and be assembled in orbit using the combined station and shuttle crews aided by remote manipulators. The resulting complex could appear as shown in Figure 6-2, accommodate a crew of 4 to 6, and provide about 36 kW of continuous power for mission equipments.

FIGURE 6-2

A MANNED SPACE STATION SERVING BOTH COMMERCIAL AND OPERATIONS MISSIONS



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A large number of non-commercial mission types are also compatible with this station concept and location, especially those involving technology development and scientific laboratory operations. The facility would also be used for government-sponsored satellite assembly and servicing operations and could serve as a base for co-sponsored international missions.

The total facility cost, in the $5 to 7 billion range, would represent a national investment that would be returned many times over in the social, economic, and technological benefits it would generate. A reimbursement program, basing user charges on their pro-rata share of the available resources (power, data, volume, crew time, etc.), would, in time, pay back the original investment plus reduce costs for government-sponsored space transportation and orbital operations.

6.1 OBSTACLES AND INCENTIVES TO COMMERCIALIZATION

The estimated market potential would appear sufficient to induce an avalanche of interest in space commercialization. With the exception of the communications industry and, to a lesser extent, the related launch vehicle and upper stage business, this has not occurred. In both successful cases, however, there were two critical factors:

1. The government-sponsored the original R&D and thereby reduced the economic and technical risks.
2. The market potential was large and well defined.

For other commercial mission opportunities, these conditions have not been fully met. However, since the potential for space commercialization is so great, the McDonnell Douglas Astronautics Company and numerous other companies and agencies have been investigating candidate commercial space opportunities since the 1960s. These investigations, as well as those recently completed with our mission analysis study teammate, Booz, Allen & Hamilton, have identified numerous issues of concern to prospective mission sponsors. These concerns are summarized in the following paragraphs.

1. Lack of Space Knowledge

Many corporations engaged in commercial business are unfamiliar with space technology and are hesitant to consider space as a new product route. Space is considered high risk.

2. Cost

The high costs for space transportation and for qualifying equipments for space travel are of major concern to commercial investors. When added to the high cost of conventional R&D, the space projects lose out. This problem has been aggravated by the lack of stable pricing policies and guarantees for launch services.

3. Time

The time required to successfully complete R&D on a new product is normally lengthy without the additional time delays associated with space technology and space transportation. This makes space commercialization less attractive.

4. Attractive Alternatives

Each proposed investment must be compared with other alternatives. For most, the ground-based alternatives offer better return at less risk and in less time. The risk-adjusted rate-of-return must be attractive to entice investment in space products and services.

5. High Cost of Space Transportation

Use of space transportation is perceived as an expensive, time-consuming, complicated process with uncertain schedules and uncertain priorities. The NASA-controlled access to space is perceived to involve extensive government controls, approvals, documentation, and procedural requirements. These are all areas of concern to prospective users. Some motivated customers are considering privately sponsored launch services to overcome these difficulties.

6. High Visibility vs. Proprietary Rights

Secrecy is essential when developing a new product. The competitive edge usually lasts only until the product can be duplicated by a competitor. Participation in a NASA space program is a highly publicized activity that could have detrimental effects. Although for some users this is welcomed publicity, for others the legal or inadvertent loss of proprietary product information is of major concern.

7. Market Promotion

The development of space as an avenue of commercialization requires marketing and sales promotion activity just as any other product or service does. The NASA agency is not adequately equipped either organizationally or legally to perform this function.

8. Inadequate Space Facilities

Until shuttle, transportation to space was a one-way trip; there was no point in considering the return of products from space. With shuttle, this is now possible, but only if the products are generated within the short mission duration available. The total mission duration is limited to about 9 days and the available payload power is limited to 7 kW (less than 4 kW if Spacelab is used). Currently, if longer-duration higher power is required, a dedicated satellite must be built for the mission. These are extremely limiting capabilities. Artists' renderings, trade publications, and news media speculation about future space systems are fascinating to corporate managers but they do not contribute to sound business planning and they do not guarantee that extended orbiter flights, space platforms, manned space stations, low-cost transportation, and satellite retrieval and servicing will be available to a commercial investor when needed. The lack of this positive commitment to new space facilities is considered the most serious obstacle to commercial development of space.

9. Overall Risk

The various issues and concerns noted above add up to an overall risk that inhibits most of industry from pursuing the commercialization of space. Their choice is to monitor the progress of space exploitation while avoiding serious commitment representing a major, long-term investment.

6.2 OVERCOMING THE OBSTACLES AND ESTABLISHING INCENTIVES

NASA already has an innovative program for sharing the costs and risks of space commercialization and for protecting the property rights of the industrial participants. It needs more publicity. The "Joint Endeavor Agreement" (JEA) has been used successfully in arranging the cooperative relationship between McDonnell Douglas and NASA on the electrophoresis project. Brown and Zoller[(1)] have published an excellent paper on commercialization incentives which explains the JEA and other forms of cooperative agreements.

Within the framework of the existing space transportation system, progress is being made to smooth and shorten the access route to shuttle flight opportunities. "Get-Away-Specials," aft flight deck installations, cargo bay payloads, and Spacelab missions are all candidate avenues for commercial R&D. To supplement the existing capabilities and policies, several other incentives are suggested:

1. The creation of an "Office of Commercial Applications" within NASA, operated on a continuous basis and empowered to promote space commercialization, using conventional marketing methods, and to establish cooperative agreements with industry, which both create incentives and protect commercial investments, is recommended as a high-priority objective.

[(1)] Richard L. Brown and Lowell K. Zoller, Avenues and Incentives for Commercial Use of a Low-Gravity Environment, NASA Technical Paper 1925, MSFC, 1981.

2. To encourage the pursuit of high-technology, space-based commercial development, a Congressional action could be initiated which authorizes special funds and incentives for investment. These could include:

- grants or low-rate loans for research and development.
- attractive tax provisions.
- guaranteed purchase of initial products.
- access to government facilities and resources to supplement R&D.
- free or reduced-rate transportation to space.
- priority assignments and guarantees on flight schedules.

3. The lack of necessary facilities in space has been cited as the most serious obstacle to full exploitation of the commercial opportunities. <u>A national commitment is needed which establishes a national space program dedicated to the exploitation of high technology and the commercial utilization of space</u>. This would include a commitment to develop a manned space station supported by the unmanned transportation and platform facilities necessary to pursue a wide range of commercial opportunities. Other features would include:

- a clear definition of the facilities and resources to be provided and the reimbursement policies affecting users.
- a firm schedule for availability.
- a total funding commitment spanning the implementation and operational phase of the program.
- specified conditions for the ultimate termination of the program or its transfer to private ownership.

The key to successful commercial exploitation of space is access to a permanent, manned space station in low Earth orbit. From this operational focal point we can proceed with the development of larger, more complex space systems; conduct the research, development, and testing required to fully understand the effects of the unique space environment; and initiate servicing and maintenance activities for our growing inventory of high-value space assets. We can conduct low-cost transportation operations to higher orbits using reusable vehicles, and, with the aid of techniques already being evaluated, we can establish new materials processing and manufacturing industries in space. The benefits to be derived from these activities will have enormous impact on the health and productivity of our society, on our technological advancement and economic growth, and on our political posture as a world leader. For the investor and entrepreneur, the commercial exploitation of space will open vast new markets with high profit potential and offer exciting new challenges in technology, financing, marketing, and management.

Appendix 1.0
TYPICAL CONFIDENTIALITY AGREEMENT

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TEXT OF TYPICAL CONFIDENTIALITY AGREEMENT
(Written by a User to Booz, Allen)

We understand that you wish to discuss with us the possibility of carrying out processes and making products in a low orbit space station. You have told us that you have reserved four specific ideas for presentation to us, and will not release them to others until we have had a chance to consider them and have expressed our lack of interest in them. You also have a variety of ideas for processes, products, and services to which a space platform may be applied, which you wish to present to us. Accordingly, you have proposed a meeting to discuss your concepts and their applicability to out specific uses, and propose that the concepts developed in the meeting shall be our property. We suggest the following arrangements.

We will hold in confidence all the confidential information belonging to you which you disclose to us both in the proposed meeting and in subsequent talks and correspondence. We will not disclose any such information to others, nor use it for any purpose of our own, to the extent that the information was unknown to us or to the public when you disclosed it. Our obligations of confidentiality and non-use shall continue until the information in question is disclosed to the public by you or is disclosed to us or to the public by another party having the right to do so.

You have suggested that the concepts developed jointly in conversations between us shall be our property, and we are pleased to accept your suggestion. Accordingly, you will hold in confidence all the confidential information belonging to us which we disclose to you, and also all confidential ideas and proposals which are jointly generated in the talks between us. You will not use any such information and concepts for any purposes of your own, nor disclose any of them to any third party, to the extent that the matter in question was unknown to you or to the public when it was disclosed to you or jointly generated. Your obligations of confidentiality and non-use shall continue until the matter in question is disclosed to the public by us, or is disclosed to you or to the public by another party having the right to do so.

If you are in agreement with the provisions set out above, please have this agreement signed by your authorized officer and return one signed copy to us.

Approved By____________________

Title__________________________

Organization___________________

Date___________________________

Appendix 2.0
FIVE POTENTIAL COMMERCIAL MISSION OPPORTUNITIES

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COMMERICAL UTILIZATION

COMMERICAL SERVICE LABORATORY

I. BUSINESS OPPORTUNITY DESCRIPTION

There has been interest generated in the development of a space-based laboratory which would, for an appropriate fee, carry out experiments to evaluate processes, make test products, or carry out various experiments which would take advantage of the unique properties of an orbiting vehicle in space. Separation of biological materials using techniques such as electrophroesis and chromatography, production of new metals, growth of unique crystals and other processes could afford various industries with samples of materials which could be evaluated to define new product opportunities. These would be made for a fee. The opportunities offered to make small amounts of unique products by space operations are of sufficient interest to command attractive fees which could support a commercial research and processing laboratory as a commerical mission. This mission offers both economic and social value. The services could create attractive profit motives to venture investors who support construction and operation. Significant social and scientific rewards would be reaped by society as micro-amounts of new materials are created for testing and evaluation as new products. The business opportunity involves identification of markets for these services which are (1) both large and long term and (2) high in profit motive.

II. MISSION REQUIRED TO SUPPORT THE OPPORTUNITY

Development of a commercial service laboratory has been initiated with the laboratory module designed by ESA for STS-9. The flight of STS-9 will provide information about functional operations, cost, and performance. Evaluation of performance should lead to opportunities to evaluate further functional values of the laboratory in 1984 and early 1985. Equipment for various operations could be designed in 1984 for testing in 1985 and sale of service in commercial trials in the 1985-1986 time period. Utilization of the limited laboratory afforded by use of some section of the shuttle until a manned station is available could produce revenue and provide demonstration of commercial value to enhance investor interest. The manned space station missions offer significant improvement over any other mode of operation in terms of relative flexibility, range of services possible, and operating cost expenses. The overall advantage of station operations would enhance the opportunity to increase the availability of services, the discovery of new products, and pilot plant performance.

III. GENERAL REQUIREMENTS ON A SPACE STATION

The general requirements for a Commercial Service Laboratory on-board a space station include the need for a man-tended facility accessible for operation, resupply, servicing, maintenance, and repair. On-line analysis and testing capability possibly including provisions for live organism test specimens must be provided. The facility should be accommodated in a separate module with controlled access containing up to 5,000 kilograms of equipment and apparatus and serviced by up to 25 kilowatts of electrical power and a corresponding amount of heat rejection. The module needs to provide a controlled environment and life support capability for up to four attendant technicians and analytical specialists. Other than normal housekeeping and operational status information the data management and retrieval requirements will be minimal when compared to communications, but this could be significantly greater than the requirements imposed by manufacturing processes.

IV. SPECIFIC REQUIREMENTS

The specific requirements imposed on a Space Station to support this mission are as follows:

Laboratory Environment

1. Local gravity: $\leq 10^{-3}$ minor disturbance excursion not critical

2. Environmental contamination: class 10,000 cleanroom with control of cross contamination of biological and chemical samples; compatible with FDA GMP requirements for clinical sample manufacture.

3. Atmosphere: variable; ultravacuum to sea-level standard atmosphere; broad range of temperature and humidty controls.

4. Lighting: constant light level of 1000 CSM, 5200 Å filtered for UV. Multiple sources for avoidance of strong shadows.

5. Crew provisions: provisions for protective outer-garments, laundering and sterilization as well as total life support for handling of new organisms and/or new chemicals. Crew washroom and cleanup and emergency eyewash and spill pickup.

Logistics and Resupply

1. Product packaging: freeze and pack up to 10 unique products per day; weight of daily production is minimal.

2. Resupply including consumables: less than 50 Kg per day.

Data Management and Communications: private CCTV voice and secure data transmission over 24-hour, daily basis.

V. ECONOMICS AND BARRIERS

Technical Status

At the present time several specific opportunities to provide laboratory services have been identified, but detailed economic analyses have not been completed. Justification for space laboratory are being pursued, but these are not yet defined. Most identified opportunities are focused on separations, but significant opportunities in other areas, e.g., metal reforming, crystal growth, cell growth, etc. also exist. These must be investigated. Primary commerical users' responsible for investment in an operation of the laboratory will have to be venture investors. A secondary users community could be a combination of industrial organizations having sufficient interest. These opportunities must be explored.

Investment and Risk

This commerical mission is characterized by very large investment capital with initial financial commitment based on market research. Typically for this type of function as much as $500 million could be required. A unique pay off situation might be created if laboratory owners can generate incentive contracts under which they participate in yield from inventions. Proprietary protection must be assured. Future guarantees as to the availability of station space and resources, logistical support for retrieval of experimental results and resupply of people and product operations must be given.

Obstacles to Commercialization

The major obstacles which can stand in the way of any commercial development of a new high technology service laboratory include the following: (1) competion from ground based facilities; (2) uncertainties of market success; (3) adequate return from the investment of capital; (4) government controls; (5) clear legal and practical grarantees of intellectual property rights.

The large initial investment may make such a venture prohibitive to private industry. Investors in commerical space operations will be concerned not just with rates-of-return on an investment, but with the risks inherent in that investment (i.e., with risk-adjusted rates-of-return). The possibility of joint activities or of leasing may permit development of more attractive investment environments for investors.

COMMERCIAL UTILIZATION
IRIDIUM CRUCIBLE PRODUCTION

I. BUSINESS OPPORTUNITY DESCRIPTION

Iridium crucibles are currently used in the production of silicon and germanium arsenide crystals that are used in specialty electronic communication and information processing equipment. The quality of these crystals is highly dependent upon the purity of the Iridium crucible. In advancing the state of the art for these components, there is a clear need for Iridium crucibles of increased purity. In the preparation of such crucibles, contact with walls and containers is the major cause of defects and impurities. It appears that purity may be significantly enhanced if prepared in space. The degree of increased purity offered by space operations may be large enough to offer attractive commercial benefits from purification and crucible refining missions.

Significant economic benefits can be foreseen. Crucible value may be improved by $500 to $1,000 per ounce. In addition, development of the process will offer opportunities not only to produce highly pure forms of other metals, but also to cast these into desired configurations within very accurate tolerances. This combined capability will enhance the ultimate economic benefits from the commercialization of this mission. The business opportunity involves introduction of high purity metals to existing markets which are (1) relatively large, (2) long term, (3) high in profit motive, and (4) currently identified.

II. MISSIONS REQUIRED TO SUPPORT THE OPPORTUNITY

The Iridium crucible commercial mission opportunity is currently in the conceptual stage. A formal and full scale commercial development program is required. This will involve tasks starting with shuttle missions to conduct experiments to establish the feasibility of containerless purification through reformation and/or casting materials from ingots or powders, process/product design, verification, and pilot operation missions in 1986 through

1988. Successful completion of these feasibility experiments would lead to production of products for use testing during the 1988 time frame. Initial production in the shuttle bay would be expected in the 1989 - 1990 time period. Sufficient quantities could be produced in the shuttle bay for sale and development of an economic return. If appropriate returns can be realized, this low level production on the shuttle may continue until the manned Space Station is outfitted.

The manned space station missions offer significant improvement over the unmanned modes of operation in terms of relative up-front costs and operating expenses. This is due to the less costly design (reduced automation and autonomy). In addition other highly purified, reformed materials could be produced in a functioning facility. This will occur when technicians are available to investigate and the equipment is available and operating to make and test other unique configurations and uses of these metals. The space station mission will provide an opportunity to produce a number of new products which cannot be developed in an unmanned operating mode. The overall advantage of station operations would enhance the opportunity to continuously increase the purity of metals and to cast new products from these at prices which permit reasonable economic return to the commercial producer.

III. GENERAL REQUIREMENTS ON A SPACE STATION

The general requirements for containerless processing to reform and/or purify and cast metals on-board a space station include the need for a man-tended production facility accessible for operation, resupply, servicing, maintenance and repair. Also required would be an off-line analytical and testing capability to provide control and assurance data needed to monitor purity and performance of metals and final products. Although final assembly and labelling could be done on Earth, continuous analysis is required to make materials of required purity and configuration.

The facility could be accommodated in a separate module with physically controlled access to protect proprietary rights. The module would have to contain up to 5,000 kilograms of equipment and apparatus and be serviced by up to 25 kilowatts of electrical power and a corresponding amount of heat rejection capability. The module would also have to make provisions for a controlled environment and life support capability for two-to-three attendant technicians and analytical specialists. Other than the power, specific resource requirements are minimal.

IV. SPECIFIC REQUIREMENTS

Specific space station requirements imposed by containerless processing to make both pure materials and to cast these in specific configurations have not been fully identified. These cannot be fully defined until design studies are completed.

Laboratory Environment

Development and production will be completed through induction heating in kilns specifically designed for this purpose. Casting may occur in the kiln or in other equipment. A vacuum or total hydrogen environment will be used. Local gravity level will be 10^{-4} or lower. The effects of minor variations remain to be defined.

Logistics and Resupply

1. Product Packaging: Not defined; probably not extraordinary although protection of surfaces will be required.

2. Resupply weight, including consumables: Up to 300 Kg per day.

Data Management and Communications

Private CCTV voice and secure data transmission, one hour per day on a daily basis

V. ECONOMICS AND BARRIERS

Technical Status

At the present time there appear to be enough specific uses of high purified metals and precisely configured metals to economically and technically justify pursuit of space production. Iridium crucibles appear to be one product which meets these requirements. In addition several other highly purified materials can be conceptualized that are excellent candidates for intensive R&D space activities in containerless production.

Investment and Risk

This class of commercial missions is characterized by large investments in both the time and financial commitment from initial identification to final full scale production and marketing of a new product. Typically, for new metal forms, the investment and development cycles can range up to 15 years and involve millions of dollars. There is no guarantee of economic success even if the market will exist at the time the development cycle is completed as planned. Under these conditions the commercial user will be reluctant to invest the needed financial resources unless his needs are clearly satisfied. These needs include such areas as proprietary protection, future guarantees as to the availability of station space and resources, and logistics support of product retrieval and resupply of production operations.

Obstacles to Commercialization

The major obstacles to commercial development of a new high technology product or process include the following: (1) competition from alternate process techniques, products and markets; (2) uncertainties of product need in the marketplace; (3) adequate return from the investment of capital and elapsed time; (4) market opportunities; and (5) clear legal and practical guarantees of intellectual property rights.

In addition to these, the space environment has higher costs that may make the emergence of new saleable products from space less certain. Operation in space forces certain minimum costs on process, packaging and distribution functions. It may be impossible to force production into a mode in which costs are driven by marketplace acceptability.

The developmental process must be made possible through joint agreements which provide opportunities for proving out feasibility and for completing process design while protecting proprietary rights and market access not only for the products which are the initial targets of the program (i.e., Iridium crucibles) but for others which are developed as commercial development and production proceeds.

As commercial production develops long term transportation and space cost agreements need to be fixed, guaranteed and commensurate with the commercial users' value-added-to-the-product by the station operations.

COMMERCIAL UTILIZATION
COMMUNICATIONS SATELLITE FACILITY

I. BUSINESS OPPORTUNITY DESCRIPTION

With the availability of a space station an opportunity exists to increase the performance and decrease the risk in several areas for commercial communications satellites. The micro-gravity environment may enable commercial satellite builders to test certain subsystems more easily than is currently being done on earth. The non-restricted area may also permit testing that is currently impossible on the ground. The economic motives for space station testing will depend on the complexity of communications satellites in the future as well as space station user costs.

II. MISSION REQUIRED TO SUPPORT THE OPPORTUNITY

The current space station/communications satellite scenario includes a Space Transportation System (STS) serviced space Station. The STS, with satellite, would be docked with the space station. After docking the satellite would be transferred to the space station, where final servicing and testing would begin. Without the volume restriction of the STS cargo bay, solar array and antenna deployments could be tested and/or completed. Final antenna alignments and subsystem testing could also be conducted. After completion of the testing and servicing the spacecraft would be mated with a geosynchronous Orbital Transfer Vehicle (OTV). This OTV would be either expendable or reusable. Once the mating has been completed the spacecraft and OTV would be deployed from the space station, and the transfer orbit injection begun.

III. GENERAL REQUIREMENTS ON A SPACE STATION

The general requirements for the type of space station described above are for a man tended facility with large areas needed for satellite testing and servicing. There are no requirements on the pressurization of the large area, and power requirements would be in the 5 kilowatt range. No specific orbit requirements are needed, beyond those needed for a base from which the final destination orbit could be reached. Usually, a 28.5° orbit (East Launch) is preferred.

IV. SPECIFIC REQUIREMENTS

1. Local gravity level: 10^{-2}g or less, minor disturbances not critical.

2. Atmosphere: not critical

3. Work area: to allow partial deployments, approximately 10m x 5m x 5m.

4. Equipment: reusable lasers, rotary table, and prisms needed for alignment.

5. Power: approximately 5 kilowatts

6. Communication: all communications equipment necessary to test in commercial communications frequencies.

V. ECONOMICS AND BARRIERS

Technical Status

Commercial communications satellites today are divided into two categories: 1) spin stabilized, and 2) three axis stabilized. Spin stabilized satellites to date have been characterized by a spinning cylindrical section with a despun antenna platform, and an uncomplicated set of deployments. The three axis stabilized satellites have been characterized by a non-rotating bus with unfurlable solar arrays and antennas. The solar arrays and antennas are usually unfurled with a complicated series of deployments before the spacecraft reaches the final on-orbit configuration.

Both types of satellites have been rapidly increasing in size (power, physical size, and capability). This trend has lead to increasing complexity of satellites in terms of deployments and more rigid pointing requirements. Good examples are the TDRSS and the INTELSAT 7.

With the development of a manned space station and a low thrust orbital transfer vehicle (OTV) problems involved with increased complexity of satellites may be reduced. The space station could act as a spacecraft test bed, allowing final verification of the communications subsystem. Final alignment of antennas and sensors could be completed without the influence of the 1 "g" environment seen on the earth. A low thrust OTV would allow certain deployments to occur under manned observation. In the event of a deployment failure the problem could be corrected before a final orbit is reached.

There are no technical breakthroughs needed in the scenarios described above.

Economic Status

At this time it is uncertain whether or not it is economically feasible to attempt final spacecraft testing and servicing on a space station. The major barrier of this type of commercial venture is whether or not there will be an adequate return on investment to the satellite user. Several factors will influence the return on investment. Some of these include:

1. Potential savings over ground based testing and servicing of satellites. This would include decreasing the risk associated with deployments.

2. The cost or user charge of using a manned space station.

The potential savings will depend largely on the direction in which commercial communications satellites grow. Continued growth in size and complexity may make the testing and servicing of commercial communications satellites on a space station feasible in the 1990's.

COMMERCIAL UTILIZATION
SEMICONDUCTOR CRYSTAL MANUFACTURING

I. BUSINESS OPPORUTNITY DESCRIPTION

Studies have shown the potential for significant improvements in the properties and yields of semiconductor materials by producing them in space. A number of space experiments have been performed on these materials and there are currently at least two companies that have been formed specifically to commercialize the manufacturing of electronic materials in space. These early endeavors are to be carried out on the Space Shuttle, but in the long term there is the potential for dedicated, man-tended production facilities in low earth orbit. Candidate materials include silicon ribbon, gallium arsenide (GaAs) ribbon or bulk, and mercury - cadmium - telluride (HgCdTe) crystals.

II. MISSION REQUIRED TO SUPPORT THE OPPORTUNITY

Depending on the specific product material (Si, GaAs, HgCdTe, etc.) and form (ribbon, rods, or small crystals), the development steps from early experimentation to full-up production will vary. For any semiconductor material, there will be a progression of experimentation, proof-of-concept tests, manufacturing process verification, full-scale production facility installation and check-out, and finally production operations. All of the effort prior to the operational production level will greatly benefit by having manned involvement. This could be accomplished by Shuttle/Spacelab sortie missions or by a long-duration Space Station. There will also be requirements for resupply, servicing, and unscheduled maintenance, which will have to be accomplished via manned operations to avoid costly and complex automatic systems.

III. GENERAL REQUIREMENTS ON A SPACE STATION

Most of the semiconductor production concepts could be achieved either with a module attached to a space station or with a free-flyer located nearby. The free-flyer has the advantages of being isolated from man-induced vibration and contamination. Production facilities would probably use a combination of a solar furnace and solar array powered electrical heating elements. Nominal resupply period is 100 days, during which operations would be largely automated to reduce the use of expensive crew time. Raw materials and other consumables could be stocked on the station to allow for more flexible replenishment (more independence from Shuttle scheduling). Resupply and servicing activities will require crew support, but there is no apparent need for any habitable, pressurized compartments. Preliminary experimental work, however, would best be done in a manned, fully equipped materials research facility. Early production runs would probably require monitoring at high data rates and manned servicing at intervals shorter than the nominal 100 day resupply period.

IV. SPECIFIC REQUIREMENTS

1. Microgravity: 10^{-3} g or less; effects of jitter and vibration are not known.

2. Attitude: Solar pointing required for free-flyers and systems using solar furnaces. The latter also benefit from higher inclination orbits (55° or higher) and have a pointing accuracy requirement of about 0.05°.

3. Cleanliness: Furnace systems will be sealed with a controlled inert gas environment, so external cleanliness levels are not critical.

4. Facility: Independent free-flyer for silicon ribbon production has been sized at 4500 kg including raw material for 240 days of manufacturing.

5. Electrical Power: 5 kw average, at 28 VDC.

6. Thermal: Passive heat rejection.

7. Data Handling: 1 kbps continuous, 20 kbps once daily.

8. Serviceability: Scheduled maintenance includes removal of processed semiconductor material and replacement of raw stock, inert gas, and other expendables.

V. ECONOMICS AND BARRIERS

Technical Status

No GaAs or HgCdTe STS flight experiments have been flown to date, but similar materials have been grown on Skylab and ASTP. The silicon ribbon concept was developed by MDAC-STL in an extensive study done in 1975-77, but no experimental work was done. Yet flight and ground research has shown that significant gains can be obtained in both material properties and production yields, and additional work on these and other semiconductor materials are planned for future Shuttle and Spacelab flights within the NASA Materials Processing in Space program.

Investment and Risk

As with any space manufacturing venture, there is a very high risk and a large investment is required, accompanied by a long payback period. Past studies have indicated the long payback period as being the major investment drawback for this type of mission. However, a company has been formed, Micro-gravity Research Associates, Inc., with the specific intent to produce and market GaAs crystals grown in space. They plan to use a research furnace, i.e. GTI Inc., another potential commercial space venture, for preliminary experimental work. Other industrial concerns have also indicated a desire to use the furnace, a sign that there are companies willing to invest on materials research in low-gravity.

Obstacles to Commercialization

The investment cycle for semiconductor processing in space is expected to be shorter than that for pharmaceutical products because no government evaluation and approval cycle is required for the new products. The main concern instead is over improvements in traditional ground-based processing techniques that would outstrip the advantages gained by going to space. This unpredictable factor, as well as the introduction of new products and processes, makes the space processing of materials aimed at the rapidly changing electronics industry a very risky venture. There are also all of the standard problems associated with commercial manufacuring in space: proprietary rights, government support/cooperation, technical problems, funding, and an uncertain market.

COMMERCIAL UTILIZATION
ELECTROPHORETIC PROCESSES

I. BUSINESS OPPORTUNITY DESCRIPTION

There has been keen commercial interest generated within the pharmaceutical community for missions which take advantage of the unique properties of an orbiting vehicle. In the separation of biological materials using techniques such as electrophoresis the product yield can be significantly enhanced by performing the separations in the near zero gravity environment of space compared to terrestrial processing. The EOS trials performed on the early shuttle flights have demonstrated throughput increases of 500 times that of equivalent ground based units. This degree of enhancement offered by space operations is sufficiently large to suggest that attractive benefits can be derived from commercial electrophoretic processing missions. These benefits include economic and social implications. The products could find attractive profit motives and offer relief to individuals suffering from health problems. The business opportunity involves expansion of markets which are (1) both large and long term and (2) high in profit motive.

II. MISSION REQUIRED TO SUPPORT THE OPPORTUNITY

The commercial development scenario involves steps starting with shuttle middeck process/product verification missions leading to production of quantities for clinical testing during the 1984 time frame. This would be followed by shuttle bay prototype production missions which would produce quantities sufficient for clinical trials and FDA approval during the 1985 - 1986 time period and then followed by low level production on the shuttle until an unmanned freeflyer is available or is supplanted by full scale multiple product operations starting up in the manned space station by 1991. The manned space station would offer significant improvement over the unmanned modes of operation in terms of both relative development and operating costs. The space station mission will also support the opportunity to allow a five-fold increase in the number of new products developed compared with the unmanned mode of operations. The overall advantage of station operations would allow the opportunity of increasing the patient availability of new products at low prices while representing excellent economic return to the commercial producer.

III. GENERAL REQUIREMENTS ON A SPACE STATION

The general requirements for commercial electrophoretic processing on-board a space station include the need for a man-tended production facility accessible for operation, resupply, servicing, maintenance and repair. Also required would be an off-line biological analysis and testing capability possibly including provisions for live organism test specimens. The facility could be accommodated in a separate module with controlled access containing up to 5000 kilograms of equipment and apparatus and serviced by up to 25 kilowatts of electrical power and a corresponding amount of heat rejection. The module needs to provide a controlled environment and life support capability for the attendant technicians and analytical specialists, the number of which would fall in the two-to four man range. Other than normal housekeeping and operational status information, the data management and retrieval requirement will be minimal.

IV. SPECIFIC REQUIREMENTS

The specific requirements imposed on the Space Station to support commercial electrophoretic processing are as follows:

Laboratory Environment

1. Local gravity level: 10^{-3}g or less, minor disturbance excursion not critical.
2. Environmental contamination: Class 10,000 cleanroom with biological contamination compatible with FDA requirements
3. Atmosphere: Sea-level standard atmosphere 20 ± 3°C 40% ± 5% R.H.
4. Lighting: Constant light level of 1000 CSM, 5200 Å filtered for UV. Multiple sources for avoidance of strong shadows.
5. Crew provisions: Provisions for protective outergarments, laundering and sterilization. Crew washdown and cleanup and emergency eyewash and spill pickup.

Logistics and Resupply (4 to 10 Factory Equivalents)

1. Product packaging: Freeze and pack up to 11-27 liters of product per day.
2. Resupply including consumables: Up to 132-330 Kg per day.

Data Management and Communications: Private CCTV, voice, and secure data transmission one hour per day on a daily basis.

V. ECONOMICS AND BARRIERS

Technical Status

At the present time there are specific proprietary products which appear to be economically and technically justifiable for space production which are being pursued by MDAC and Johnson & Johnson under a joint endeavor agreement with NASA. In addition there are several other potential areas that are excellent candidates for intensive R&D space activities on other products for electrophoretic processing. As commercial production develops, long term transportation and space cost agreements need to be fixed and guaranteed commensurate with the commercial users' "value-added-to-the-produce" by the station operations.

Investment and Risk

This class of commercial mission is characterized by very large investments in both elapsed time and financial commitment from initial identification to final full scale marketing of a new product. Typically for a single new pharmaceutical the investment cycle in time and money can range up to 10 years and tens of millions of dollars. There is an additional risk in that once a new product is pursued there is no absolute guarantee of success after the cycle has been completed. Under these conditions the commercial user will be reticent to invest the financial resources unless his needs are clearly satisfied. These needs include proprietary protection, future guarantees as to the availability of station space and resources, logistical support of product retrieval and resupply of production operations to mention a few.

Obstacles to Commercialization

The major obstacles which can stand in the way of any commercial development of a new high technology product or process include the following: (1) competition from alternate process techniques, products and markets; (2) uncertainties of product success in the marketplace; (3) inadequate return from the investment of capital and elapsed time; (4) government controls (such as FDA approval of the final product) and (5) unclear legal and practical guarantees of intellectual property rights.

Beyond these there are additional obstacles that will be encountered in the development of products in space.

Fundamental differences exist between ground-based and space investment opportunities which can negatively affect the risk-adjusted rates-of-return for space investments and stand as barriers to participation in such investments by private enterprise. These differences include: (a) the initial investment needed to verify processes in space is much greater, (b) the rights to property and data are less clear, and (c) there is greater reliance on the government's uncertain schedules for facilities support. In order to stimulate private investment in space, these barriers must be eliminated.

The first barrier is the high cost of space verification. A company would consider processing in space rather than on the ground only if the uniqueness of the space environment would offer a major advantage over traditional ground-based production methods and would offset the increased cost, or permit the production of an entirely new or a greatly improved product.

The investment and payback projection for a typical fifteen year Earth-based development project will include the R&D expenditures amortized along with the plant costs over the first five years of sales. If this same project required a process operating in space, the space verification costs would have to be amortized along with the other development expenses in the same five years of sales. This radically changes the investment and payback projection. Because of the substantial increase in the payback requirements (e.g., amortization expenses would increase as much as 50%), either the price of the product would have to be so high that the market would drop and not support the added costs, or the payback period would have to be so extended that it would be impractical from a sensible business standpoint. Either development would limit the commercialization of valuable new products. In addition to the high investment costs of verifying the process in space, the fact that these costs occur early in the program means high investment at high risk.

Since space verification costs cannot be avoided, the creation of incentives to overcome this barrier is appropriate. NASA recognized this need and provided such an incentive in their joint endeavor policy. They have agreed to provide shuttle flights and support in order to lower initial program expenditures associated with space verification. Specific arrangements will vary from company to company, however funds are not exchanged between NASA and the private sector. This type of support does not remove the burden of risk from the shoulders of industry. Industry still carries the conventional risk typical of ground-based R&D programs. NASA's support does, however, allow space to become a competitive environment for private investment.

The second barrier to participation in space investments concerns how companies can protect their rights to the data and the products they develop. The extent to which such rights should be protected should depend upon how much an individual company is willing to invest in the effort to develop the technology, processes, and products. It should be possible, however, for a company to fully protect its data rights and its ability to license the processes or products developed at its own expense.

The third barrier is industry's dependence upon the government's scheduling and the availability of its support services. Although significant technology verification and pilot demonstrations can be conducted with the current space transportation system, ultimate commercial success will depend upon access to continuous on-orbit operation. For most commercial users a substantial reduction in electrical power requirements and a significant reduction in weight requirements will result when plant operations in in space are continuous. Therefore, the economic attractiveness of products will depend to a great extent upon some assurance that the required facilities and services (e.g., heat, light, and power) will be available to support privately financed processing equipment. NASA's future plans, though at best funded on only a year-to-year basis, include such support facilities as a manned space station. If such support facilities are not available when needed, costly delays to a new commercial program could be fatal. A private company with a heavy front-end investment cannot afford to mark time while yearly funding and scheduling problems await OMB and Congressional action. Early and substantial investment in government space assets must be made to demonstrate clearly that this barrier can and will be removed.

Even though these classes of obstacles are formidable, mechanisms now underway and being tested on such programs as EOS will make potential pharmaceutical missions more attractive to the commercial user community.

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Appendix 3.0

LISTING OF USER CONTACTS

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USER CONTACTS MADE BY MC DONNELL DOUGLAS

1. Tom Harford, AIAA Headquarters 19 Aug 82
   - Provided a list of research executives from the Fortune 500 group who have attended the NASA/AIAA series of seminars on the "Tracking of the Space Revolution".

2. Stover Babcock, Tucker Anthony 09 Sep 82
   - Key to improved electronics is material purity.
   - DoD VHSIC and VLSI programs may have some interest.

3. Ron Phillips, NASA Headquarters 08 Sep 82
   - Referred us to the AIAA-Fortune 500 group and to Lou Testardi's office.

4. Richard Brown, NASA MSFC Commercial Development Office 09 Sep 82
   - Referred us to MSFC Space Station Office (common contact point for all study contractors).

5. Lou Testardi, NASA Headquarters Materials Processing Office 13 Sep 82
   - Referred us to the AIAA-Fortune 500 group and the MSFC Commercial Development Office.

6. Nat Kessler, A. E. Staley MFG Co. 14 Sep 82
   - They have some interest in electrophoretic purification, but most of their products are relatively low-valued.
   - Might be interested in doing research in space using electrophoresis.

7. Lamont Eltinge, Eaton Corporation 16 Sep 82
   - Degree of improvement in semiconductors by processing in space is still uncertain. Basic research on the effects of low-gravity is required (combustion, distillation), and they would be interested in using a commercial space research facility.

8. Edward Young, DuPont 17 Sep 82

- They have Technical Exchange Agreement (TEA) with NASA, with a primary interest in research on nickel alloys and chemical synthesis. There are no obvious materials that can be commercially manufactured in space.

9. Nicholas Franco, Bethelem Steel 22 Sep 82

- Their interest is in basic research (coking, graphite morphology).
- They have reserved in "Get-Away Special" but have no specific plans for it.

10. Richard Randolph, Microgravity Research Associates, Inc. 22 Oct 82

- Expect to sign Joint Endeavor Agreement soon. Their company was formed for the purpose of producing high-quality gallium arsenide crystals in space. Initial work may be done in GTI furnace.

11. John Benjamin, INCO 26 Oct 82

- Research is needed into effects of space environment

12. Roger Fountain, MDAC-STL Materials and Processes 29 Oct 82

- Most composites and polymers have relatively low cost per unit mass. Certain trace ingredients and catalysts, however, may have their value increased by purification or some other processing done in space. Drug intermediates are another class where purity is important.

13. James Graham, John Deere and Company 22 Oct 82

- Their TEA involves studies of graphite formation in cast iron, which affects the physical properties of the finished product. Primarily a research program, with no immediate commerical applications. They have an interest in using the GTI furnace.

14. Bob Stacy, Bob Rice, MDAC-STL Electro-Optics 03 Nov 82

- Improvements in semiconductor crystals are needed not only in reducing defects, but in increased purity, which may or may not be addressable by space processing. Best areas for space research and development include HgCdTe, YAG, GaAs crystals and diamond substrates.

15. K. K. Sankaran, MDAC-STL Materials and Processes 01 Dec 82

- Containerless processing in space may be useful in certain titanium alloys. Relationship of rapid solidification technology to space-based processes is not yet understood.

16. Don Ames, McDonnell Douglas Research Labs 10 Sep 82

- Early space experiments (Skylab, ASTP) were not always well designed. Best prospects for space work include HgCdTe, organic crystals, and specialty polymers. Doesn't see much benefit for chemical/petroleum industry (few high-valued products).

17. Dave Keaton, GTI Corporation

- Developing an isothermal, 1500°C, modular furnace under JEA with NASA. Primarily a research facility with a capability to produce small amounts of marketable goods. If early MPS results are promising, he sees a big demand for a space manufacturing research facility.

18. Esker Davis, GTI Corporation 07 Dec 82

- Interest in commercial space solidification investigations is continuing to develop.

19. James Rose, McDonnell Douglas Sep 82 Thru April 83

- STS-4 verified improved performance of electrophoresis. A MDC/ Johnson & Johnson proprietary product development points to a large market for output of the electrophoresis processing facility.

USER CONTACTS MADE BY GEOSCIENTIFIC SYSTEMS (DR. JACK GREEN)

1. Officers and Board of Directors of the GEOSTAT COMMITTEE - 4 FEB 1983:

PRESIDENT	Dr. Frederick B, Henderson III, GEOSAT
VICE PRESIDENT	Dr. Oliver Warin, GEOSAT

Dr. J. M. Allen, COMINCO
Dr. Anthony Barringer, BARRINGER RESOURCES
Dr. Ken Ciriacks, AMOCO INTERNATIONAL
Mr. Jon Davidson, SUPERIOR OIL
Dr. Jerome Eyer, GRACE PETROLEUM
Dr. Normal Guinzy, MOBIL R&D
Dr. Michel T. Halbouty, HALBOUTY ENTERPRISES
Dr. Leonard Jacob, Jr., ALCOA
Mr. H. A. Kuehnert, PHILLIPS PETROLEUM
Mr. Cole McClure, BECHTEL
Dr. Marcus Milling, ARCO
Dr. Robert Millspaugh, CITIES SERVICE
Mr. William Moran, UNION/MOLYCORP
Mr. Robert Porter, EARTHSAT
Dr. G. Wesley Rice, CONOCO
Mr. W. T. Storie, Jr., SUN EXPLORATION
Dr. James Taranik, MACKAY SCHOOL OF MINES

2. Other Contacts

Dr. Peter Glaser, Vice President, ARTHUR D. LITTLE CORP.
1 FEB 1983

Dr. Jack Salisbury, EROS Program, U.S. GEOLOGICAL SURVEY
2 FEB 1983

SEVENTEEN KEY USER CONTACTS MADE BY BOOZ, ALLEN & HAMILTON, INC

(Dr. Myron S. Weinberg, PhD.)

1.	Iridium Crucibles	Dr. Lawrence Thomas Johnson Matthey Inc.
2.	Fee-for-Service Laboratory	Proprietary (1)
3.	Biological Processing	Dr. David Dennan Eli Lilly Research Laboratories
4.	High-Performance Catalysts	Dr. Lawrence Thomas Johnson Matthey Inc.
5.	New Biological Product	Proprietary (2)
6.	Biologically Active Membranes	Proprietary (1)
7.	New Plastics	Proprietary (1)
8.	Bone Replacement	Dr. John Kay Calcitek
9.	Metal Reforming	Mr. William Bosch Special Metals Corporation
10.	Hazardous Waste Management	Dr. William Carpenter The Monsanto Company
11.	2nd High Performance Catalyst	Proprietary (2)
12-14.	3 New Metal-based Products	Proprietary (1)
15.	Gallium Arsenide Crystals	Mr. Erwin Branahl McDonnell Douglas Astronautics
16 & 17	Two Products Based on Molecular Biology and Genetic Engineering	Proprietary (1) Proprietary (2)

(1) Public disclosure of this contact at this time would seriously jeopardize future development of this contact. Booz, Allen is prepared to disclose this information to NASA under appropriate circumstances.

(2) Booz, Allen's agreement with this user does not permit disclosure of this information.

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