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# Second Symposium on Space Industrialization

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*Proceedings of a symposium held at  
Huntsville Hilton Inn  
Huntsville, Alabama  
February 13-15, 1984*





# Second Symposium on Space Industrialization

*Edited by*  
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*Marshall Space Flight Center, Alabama*

Proceedings of a symposium sponsored by  
NASA Marshall Space Flight Center,  
The American Institute of Aeronautics and  
Astronautics, and The University of Alabama  
and held at Huntsville Hilton Inn  
Huntsville, Alabama  
February 13-15, 1984

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## FOREWORD

As Earth's civilization evolves, mankind moves sporadically into new domains, bringing along a panoply of natural activities. One activity that invariably accompanies man's advance into new situations is a pursuit of commercial ventures. Thus, explorers, soldiers and traders all participated in the post-Columbian transformation of the Western Hemisphere. Likewise, man's mastery of nuclear energy quickly embraced scientific, military and industrial dimensions.

In this spirit, no question has ever existed as to whether space activities would have a commercial component. Indeed, communication satellites became viable remarkably soon after the first scientific satellites. The pertinent question is whether and how the commercialization of space can be paced and guided for the optimum benefit to mankind and the United States. To address this question, a prerequisite is an objective assessment of current commercial space ventures and an authoritative evaluation of future prospects. One way to assemble this understanding is through a meeting of key individuals who are knowledgeable because of their personal involvements. For these general objectives, a Symposium on Space Industrialization was sponsored in 1976 by the Marshall Space Flight Center and the Alabama-Mississippi Section of the AIAA. The proceedings of that symposium provided a milestone for commercial development in space (NASA CP-2026).

Early in 1984, the circumstances became particularly auspicious for a Second Symposium on Space Industrialization. President Reagan, in his July 1982 statement of space policy had called for the United States to obtain economic benefits through the exploitation of space and to expand private sector investment and involvement in civil space and space-related activities. NASA and the President's staff responded to this call by studying the available options and recommending appropriate actions. This led to President Reagan's further endorsement of space commercialization and of a space station in his January 1984 State of the Union message. The Second Symposium came immediately after this message, on the crest of the wave of interest generated by the Administration's pronouncements.

The Symposium was most fortunate to have as its principal speaker, Mr. Craig L. Fuller, Assistant to the President for Cabinet Affairs. He brought an authoritative interpretation of the Administration's policies and attitudes. Mr. Fuller also conveyed the genuine enthusiasm of President Reagan for national utilization of space.

Senator Jeremiah Denton of Alabama introduced Mr. Fuller. In his remarks, Senator Denton presented a congressional view of the subjects treated in the Symposium.

The prospect of a permanently manned space station within a decade, as announced by the President, gives further impetus to space industrialization. Those enterprises that require no manned intervention, such as communications spacecraft, have flourished already. Other enterprises, however, have developed more slowly because their full automation is too costly or difficult. Materials processing is often cited as an example of such a discipline. The operational maturity of the Shuttle, and later a space station, will make many ventures practical that were previously not so.


Under these favorable circumstances, the Second Symposium on Space Industrialization met in Huntsville, Alabama, on February 13 through 15, 1984. Its sponsors were the Alabama-Mississippi Section of the AIAA, the Marshall Space Flight Center of NASA, and The University



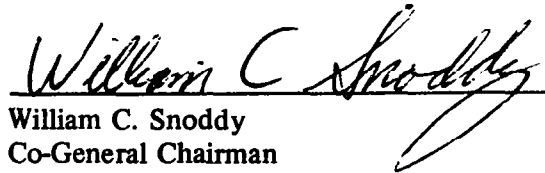
of Alabama in Huntsville. The Organizing Committee included representatives from a still broader group of institutions.

An agenda of distinguished invited speakers covered the status of commercial space ventures and opportunities for the future. Discussion of these papers was spirited and informative. A poster session gave other participants a chance to contribute pertinent information and opinions.

This volume contains the Symposium proceedings. It preserves for the participants and others a record of the material presented. The organizers hope that in future years, the leaders active in space commerce can look back to the Symposium and credit it for providing seminal insights.



Charles A. Lundquist  
General Chairman



William C. Snoddy  
Co-General Chairman

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# **NASA'S POLICY AND PLANS FOR SPACE COMMERCIALIZATION**

by

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## **ABSTRACT**

The advent of the Space Transportation System and the new initiatives by this Administration are providing an increased impetus to the Commercialization of Space. This paper reviews NASA's past and on-going role in space industrialization and discusses the NASA Commercial Space Policy designed to enhance the opportunity for commercial involvement in the use of space. This was mandated by President Reagan in his National Space Policy of July 4, 1982, where the development of "a climate conducive to expand private sector investment and involvement in civil space activities" was made a principal objective of the United States Space Program.

# NON-U.S. APPROACHES TO SPACE COMMERCIALIZATION

by

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## ABSTRACT

This paper describes the approaches to the commercialization of space taken by the four foreign countries most active in the field -- Canada, France, the Federal Republic of Germany and Japan.

National space program elements with commercial potential are examined in the context of national industrial and science policies, with special attention to objectives, timetables, and budgetary priority relative to other sectors.

The role of the European Space Agency in attaining national and regional commercialization objectives is also examined.

## TEXT

### INTRODUCTION

Foreign space commercialization policies do not exist in a vacuum. Typically, the broad policy directions which influence the content of these policies are derived from national industrial policies, particularly those concerned with encouraging innovation and the development of internationally competitive high-technology industries.

Among the countries which are the focus of this paper, there is wide variation in policy approach. Since the post World War II recovery, the Japanese government has specified objectives and priorities for the economy, and has implemented its perceptions through what is, for the non-Socialist world, an unprecedentedly close business-government relationship.

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The writer is indebted to his colleagues in the International Affairs Division of NASA Headquarters for their unstinting help in the preparation of this paper. Needless to say, they are hereby absolved from any responsibility for errors of omission or commission, which must fall fully on the writer.

Views expressed in this paper are solely those of the writer, and do not necessarily reflect the views or positions of the National Aeronautics and Space Administration.

In the Federal Republic of Germany, on the other hand, and particularly in recent years, it appears that the government has made a fundamental decision to avoid the role of picking "winners," and to let the marketplace determine the success or failure of individual sectors. German officials acknowledge that there are many exceptions, particularly in the case of subsidization of troubled or declining industries, but argue that these measures represent a necessary adjustment to changing market conditions rather than a "positive" industrial policy.

France has historically adopted an approach somewhere between the German and Japanese patterns, combining pervasive government ownership in key sectors with, generally, a much less extensive government planning and coordinating role than practiced from Tokyo.

Canadian industrial policy, reflecting special factors of geography, relatively limited population and consequently restricted internal markets, has adopted a unique focus on the issues of industrial independence and development of indigenous capacity to meet special Canadian needs.

#### SPACE BUDGET TRENDS

To begin the discussion of non-U.S. space commercialization programs, a useful first approximation of the relative priority of space in the eyes of key foreign governments may be gained from a comparison of space budget levels over the last few years. The following table presents this comparison. Individual countries' currencies (or in the case of ESA, ESA Accounting Units) have been used instead of the more familiar US\$ figures because the dramatic strengthening of the US\$ over the last two years would have distorted the trends portrayed by the chart. For comparison purposes only, a US\$ figure equivalent to the 1983 budget level, expressed in terms of the end-1983 exchange rate, is included in the entry for each country.

From the table, the most striking conclusion to be drawn is that when these budget levels are corrected for inflation, only the French space budget has actually increased in real terms since 1979. ESA, Japan and the Federal Republic of Germany more or less held their own, while Canada showed a real decline. The Canadian result is somewhat distorted, however, because Canada employs a rolling four year budgeting approach, and in December 1981 Canada increased its space budget by one third, to C\$476M over the 1981-1985 period. This increase is not fully reflected in a statistical series ending in 1983.

Table 1.

<u>Country</u>	<u>Space Budgets</u>						<u>1983(US\$M)</u>
	<u>1979</u>	<u>1980</u>	<u>1981</u>	<u>1982</u>	<u>1983*</u>	<u>% Chg.</u>	
Canada (C\$M)	100.0	100.0	96.7	136.0	106.2	+6.2	84.1
France (MFFr)	1649.5	1907	2617	3098.5	3668.6	+122.4	434.7
ESA* (MAU)	636.6	625.8	603	673	788.6	+23.9	771.2
Japan (MYen)	99,498	102,005	104,995	108,468	113,389	+14.0	484.4
Germany (MDm)	653.7	726.4	805.6	847.3	768	+17.5	282.4

\* The ESA budget is funded about 36 percent by France and the Federal Republic of Germany, hence the ESA line reflects double counting on the order of 280 MAU (US\$274M).

## FEDERAL REPUBLIC OF GERMANY

In his foreword to the Fourth Space Programme of the Federal Republic of Germany, Federal Minister for Research and Technology Dr. Heinz Reisenhuber said, "One goal of German space policy is to accelerate the utilization of scientific knowledge for the manufacture of commercial products ... The space policy of the Federal Government aims to secure future employment by supporting highly-developed space flight technology as a pace-maker for future innovations."

### Budget Levels and Budget Priority

In 1982, the German budget for space activities constituted Dm 847M, or 12.9 percent of the budget of the Federal Ministry for Research and Technology (BMFT) . Of this sum, Dm 403M or 44 percent was the F.R.G. contribution to ESA.

In 1983, the BMFT's budget for space declined to Dm 768M; about 50 percent went to ESA. The 1983 BMFT budget presents a typical picture of the relative priority of space, with energy research allotted 39 percent of total funding, compared to 11 percent for space. No other sector received comparable emphasis, although both electronics/data processing and health/environmental research were budgeted to a share of about 7 percent each.

For 1984, BMFT's planned space budget allocation is Dm 810M. Reflecting the reduction in BMFT's involvement as communications satellite programs near operational status, R&D support in this field is to be cut by 41 percent, to Dm 68 million. Space accounts for 11.4 percent of BMFT's 1984 draft budget. Current BMFT policies favor increased industrial involvement in research and development, and changes in the tax structure and other indirect measures are being implemented to encourage such investment, rather than relying on increases in direct government support. BMFT's direct R&D project support (all sectors) is to be reduced from Dm 3.5 billion in 1982 to Dm 2.8 billion in 1984.

In 1984, for the first time, funding will be made available for space activities by agencies other than BMFT. The all-agency total is to be Dm 1008M. The German contribution to ESA will reportedly include Dm 39M from the Ministry of Transport for EUMETSAT. The 1984 national draft budget also reportedly includes funding by the Ministry of Posts and Telecommunications for communications satellites, totalling Dm 70M for TV-Sat and Dm 135M for development of the DFS (Postsat) operational communications satellite, which will be used mainly for telephone communications. Taken together, these non-BMFT contributions to operational programs constitute virtually the entire increase in the German space budget for 1984.

## Space Commercialization Priorities and Efforts

Commercialization plays a significant role in the overall objectives of the Federal Republic's space program. The general objectives stated in the Fourth Programme are:

- Promotion of fundamental research, partly as a contribution toward the cultural development of the nation and partly to guarantee the long-term efficiency of the economy.
- Innovation by applying space technology above all to public services, primarily with satellite communications and earth observation.
- Strengthening German industry's competitiveness by direct commercial application of space technology.

Central elements of the Programme with commercial implications include:

- Improvements in the performance and economics of satellite communication and remote sensing systems until it has been demonstrated that they are ready for specific applications; introduction of fully-operational systems by State users;
- Implementation of a trial phase using space as a laboratory for experiments concerning materials science, processing techniques, and bio-medicine, whether in the manned Spacelab or on re-usable space platforms;
- Development and construction of the space transport and orbital systems needed to perform those tasks.

Reflecting these priorities, the BMFT space budget in 1982 committed Dm 70M to development and construction of communications satellites, and Dm 35M to Spacelab utilization. Communications satellite and Spacelab research together amounted to only 12.4 percent of the total (excluding, however, amounts for these purposes in the DFVLR budget, which runs about 25 percent of the BMFT total).

In discussing Germany's approach to space applications, the Fourth Programme dwells at some length on the practical benefits of space research.

The space programme is intended to support industry in its efforts to develop space transport facilities and operational applications satellite systems capable of satisfying the economic and technical requirements imposed by the likely market and demand and, subsequently, to make those systems available to users for a variety of public services. It should help the German space industry to win a fair share of the world market, and thereby create jobs in high-technology industries displaying considerable potential for innovation.

To ascertain BMFT's commercialization priorities more clearly, it is useful to consider a few key program areas in some detail.

A. Spacelabs -- The largest single undertaking in BMFT's current space budget is the D-1 Spacelab mission, managed by DFVLR, the German Aerospace Research Establishment, and scheduled for flight in September 1985. Total cost of the D-1 mission is estimated at Dm 323.5M (1981 funds), of which Dm 61M is earmarked for materials science hardware and experiment support; Dm 110.7M for payload integration, payload operations and management costs; and Dm 128.4M as payment to NASA for STS services. A reflight, called D-2, and an all-pallet Spacelab science mission, D-4, are also being proposed. The payload for D-1 is divided between materials science, remote sensing (both microwave and visible light), life sciences and a navigation experiment, NAVEX. In order to secure exemption from the STS and Spacelab use fees (a non-trivial but proportionately minor part of the total cost of D-1), BMFT has elected to fly 93 percent of the D-1 payload (all but NAVEX) under a NASA policy which waives those fees for payloads without near-term commercial implications, while affording NASA access to the data from them.

B. Space transportation systems -- The F.R.G. supports the Ariane program through its ESA contribution and through 19.6 percent ownership of Arianespace, the quasi-private European launch vehicle firm. It also supports in a limited way the efforts of OTRAG to develop a commercial sounding rocket capability which may eventually evolve into a commercial launch capability for small payloads to low earth orbit.

A high priority in the German applications program is the development of reusable space platforms. EURECA, ESA's reusable carrier, is under development based on the SPAS technology of Messerschmitt-Boelkow-Blohm (MBB), and is scheduled for an October 1987 reimbursable Shuttle launch and retrieval in May 1988. In April, 1981, NASA and BMFT signed a Memorandum of Understanding on utilization of the STS, covering Spacelab missions and other future activities. In the Programme, BMFT noted that "the operational advantages of



manned transportation systems will be a key factor in the further development of orbital systems."

C. Materials science -- The Programme calls for the development of new manufacturing techniques and materials "by selective exploitation of the unique physical conditions encountered in space." In practical terms, however, BMFT apparently believes that materials processing in space is still in the stage of fundamental scientific research. The decision with regard to the handling of data from the D-1 mission seems to confirm this view.

The German materials science program includes sounding rocket flights, small Shuttle payloads, Spacelab experiments and future reusable carrier payloads. The sounding rocket program, called TEXUS, involves 1-2 launches per year from ESRANGE in Sweden, in cooperation with ESA and the Swedish government. Germany is also making active use of NASA's Small Self-Contained Payload (SSCP) program and has purchased its own SSCP containers for additional flights of MAUS (automated materials processing investigations payloads). NASA and BMFT have agreed to exchange results from NASA's Materials Experiment Assembly (MEA) and BMFT's MAUS.

D. Communications and Broadcast Satellites -- Germany and France jointly developed the Symphonie experimental communications satellite which was placed in orbit in December 1974. Germany and France are now cooperating in the development of TV-Sat and TDF-1 respectively, direct broadcast satellites scheduled for first launch in 1985 (aboard Ariane) and operational status in 1987. The Ministry for Posts and Telecommunications will operate TV-Sat, and has also begun development of the operational German telecommunications satellite (DFS).

In September, 1981, the French and German governments concluded an agreement on technical and industrial cooperation in marketing and exporting the TV-Sat/TDF-1 design. The TV-Sat/TDF-1 design was selected by Sweden for its Tele-X system, and is currently being actively marketed to the Chinese.

The TV-Sat direct broadcast satellite is reportedly planned to be the last BMFT-sponsored communications satellite project. As mentioned above, the Federal Ministry of Posts and Telecommunications is also contributing to TV-Sat, and full responsibility for the DFS system will rest with the PTT. BMFT reportedly intends to focus on new technology development.

E. Remote sensing -- Candidly, the Fourth Programme notes that "doubts about the economics of this type of satellite can be expected to persist for a long while to come. Nevertheless, Europe and the Federal Republic of Germany would be wrong to cut themselves off from these activities ..."

The German program gives priority to the development of long-term strategies for using satellite data in operational applications. A German national remote sensing center has been established at Oberpfaffenhofen, which will also form part of the European remote sensing data network.

Germany has developed several remote sensing instruments for flight on the Space Shuttle: The Microwave Remote Sensing Experiment (MRSE), the Metric Camera and the Modular Optoelectronic Multispectral Scanner (MOMS). The first two flew on Spacelab 1 and are scheduled for reflight on D-1, while MOMS flew on the first two flights of SPAS. SPARX, a joint venture involving MBB and the U.S. Communications Satellite Corporation, is negotiating for a flight of the SPAS/MOMS combination on an early STS flight, and plans to market the resulting data commercially.

F. Meteorology -- German involvement in this field is through the ESA Meteosat 1 and 2 programs, and through its participation in EUMETSAT, the European operational consortium.

#### Government-Industry Relations and Space Commercialization

There are only two primary aerospace companies in Germany: MBB (with which VFW-ERNO merged at government insistence, in an apparent effort to strengthen the German competitive position in bidding for contracts worldwide) and Dornier. German government space contracts are routinely reserved for these firms, and for German subcontractors. The BMFT in general favors initiative on the part of the German aerospace industry, and is willing indirectly to assist firms with such development efforts as MBB's SPAS, where BMFT funded experiment development and then leased space on the SPAS to fly those experiments.

There is a persistent rumor in the U.S. that German industry is actively pursuing materials processing research for near term industrial applications. In fact, while German industry is indeed participating in such research, the work is apparently being done with government, not industry, funds. Industry in Germany does not appear convinced as yet that the space environment offers sufficiently attractive opportunities for profit to warrant significant investment.

#### FRANCE

Since the establishment of the Centre National d'Etudes Spatiales (CNES, the French space agency) in 1962, French government policy has emphasized the industrial applications of

space research. As set forth by the French government in October 1981, the French space program has, as principal goals:

- consolidating French industry's position in space applications;
- improving France's share of international markets for launch services, satellites and associated ground services and equipment, and;
- preparing France, through a major basic technology R&D effort, for changes that "are likely to profoundly modify the design and economics of space systems during the 1990-2000 time frame."

Budget Levels and Budget Priority

Late last year, CNES proposed to an Interministerial Council plans for a major expansion of French spending on space, from a level of FF 3.5B in 1983 to 4B in 1984 to about 5B in 1990. The plan, which remains under consideration by the French government, continues emphasis on telecommunications and direct broadcast satellites and remote sensing, as well as calling for the development of Ariane 5 under ESA auspices. Several configurations are under study, all relying on advanced hydrogen-oxygen technology. In a significant departure, the CNES plan also proposes the development of Hermes, a small reusable manned spacecraft to transport astronauts and supplies to and from an orbital platform; previously, the French had held that manned spaceflight was an expensive luxury, unnecessary to their space objectives.

Table 2.

French Space Budget, 1981-1983 (M FF)

<u>Line Item</u>	<u>1981</u>	<u>1982</u>	<u>1983</u>
Multilateral cooperation	1003	951.5	1286.2
Bilateral cooperation	485.1	475.9	463.6
National program	334.8	628.6	741
Program support (*)	555.1	802.5	882.3
R&D	55.3	95.1	125

Analyzing CNES's 1983 budget in other terms, its May 1983 publication "France in Space" gives the following breakdown of 1983 funding by objective:

Table 3.

<u>1983 CNES Budget by Discipline</u>		
<u>Objective</u>	<u>Amount (MFF)</u>	<u>percent</u>
Sciences	325,700	9.38
Applications	1,735,971	50.02
o telecommunications	439,400	12.66
o earth observation, meteorology, etc.	778,471	22.43
o launch services/equipt.	515,100	14.84
o misc. applications	3,000	0.09
R&D	125,000	3.60
Program support	1,284,475	37.00

Two key trends are evident from these figures: the sharp increases in the French national program (principally related to the SPOT remote sensing program), and the heavy commitment to applications programs, a natural result of the French government's focus on the operational and commercial exploitation of space systems.

Space Commercialization Priorities and Efforts

A number of current programs are at the core of the French commercialization effort.

A. Launch vehicles -- ESA's Ariane launch vehicle program was begun at French initiative, and France contributed 62.5 percent of the required capital for the development of the Ariane 1-3 series; in return, under ESA's industrial participation principles, CNES was made prime contractor for the development effort.

Ariane currently is near the end of the "promotional series" of ten launches. Beginning in 1984, the Ariane 2 and 3 vehicles will become available, and will be operated by the quasi-private company Arianespace, which is energetically marketing their services, together with those of Ariane 4, expected to be available in 1986. The French controlling share

of Arianespace ownership is 59.25 percent, of which CNES alone holds 34 percent. France is also contributing 57.1 percent of the \$241 million authorized development cost of Ariane 4. It is anticipated that France will carry a similar share of the cost of developing Ariane 5.

In addition, France operates the launch facility at Kourou, French Guiana, which is the dedicated launch site for the Ariane vehicles. That and other extensive interpenetration between CNES and Arianespace (the Director General of CNES, for example, is also President of Arianespace) underscores the French financial support of and commitment to the successful commercialization of the Ariane vehicle.

B. Communications and broadcast satellites -- CNES is prime contractor to the French PTT for the Telecom I national telecommunications satellite program, which is expected to become operational in 1985. The satellite system will provide C, X and Ku-band services, including digital communications, conventional telephone and video traffic, both within France and with neighboring countries and French overseas territories. The French government points with special pride to the selection of SNIAS (Aerospatiale) as prime contractor for the Arabsat regional communications satellites, citing that contract as the first break in U.S. dominance of the world market.

As already discussed, France and Germany are engaging in parallel development of the TDF-1/TV-Sat direct broadcast satellites, with Aerospatiale and MBB collaborating on the spacecraft proper while Thomson-CSF and AEG Telefunken are responsible for the communications payload. The consortium has already achieved one export success with its selection as prime contractor for the Tele-X DBS system. CNES is also an active participant in ESA's ECS and MARECS programs, and a moving force in the establishment of the EUTELSAT organization to operate the ECS satellites on a commercial basis.

C. Earth observation -- Using a CNES-developed multimission bus, the SPOT satellites, the first of which is scheduled for launch in 1985, will carry high-resolution pointable instruments to acquire multispectral earth resources data with 20m spatial resolution and panchromatic images with 10m resolution. SPOT will be capable of providing stereoscopic images through cross-track viewing. CNES has taken the initiative to establish Spot Image to market SPOT data collected by the French ground station or by direct reception. France is also providing the satellite bus and payload elements for the ESA ERS-1 microwave remote sensing satellite.

D. Materials processing -- Exploration of the potential of the micro-gravity environment has not been a major priority of the French program to date, although France supplied the gradient heating facility for Spacelab-1, and one of the tasks carried out during the first Franco-Soviet manned flight was the production of special alloys involving components of widely varying density which are not miscible on earth.

Government-Industry Relations and Space Commercialization

The French aerospace industry's total capacity is about 50 percent state-owned. SNIAS (Aerospatiale) is the centerpiece of the governmental sector, while Dassault-Bruguet, Engins Matra and Thomson-CSF remain in the private sector. French government space procurements are reserved to French firms.

The unique aspect of the French government's approach to space commercialization is the role that CNES has played since 1973 in the establishment of business organizations to pursue commercial opportunities arising from its space program. The following table, drawn from the French magazine Air et Cosmos, lists these CNES "filiales" (literally, subsidiaries or branches).

Table 4.

<u>CNES's Commercial Subsidiaries</u>			
<u>Organization</u>	<u>Founded</u>	<u>Ownership</u>	<u>Capital</u>
Aerospace Remote Sensing Development Organization (GDTA)	7/1973	CNES 20%	--
PROSPACE	7/1974	CNES 12%, France 100%	--
Satel-Conseil	7/1978	CNES 33%, France 100%	--
Arianespace	3/1980	CNES 34%, France 59%	180M FF
Arianespace Inc. (USA)	12/1982	Arianespace 100%	--
Spot Image	7/1982	CNES 39%, France 90%+	25M FF

Spot Image Corp. (USA)	1/1983	Spot Image 100%	--
Intespace	1/1983	CNES 45%, France 100%	6M FF

Some of these organizations are familiar to American readers while others may require some explanation.

Prospace is a groupement d'interet economique (GIE), composed of CNES and 43 French industrial firms active in the space sector. Its objectives are the promotion of its members' products on the world market and the identification of new markets for French space products, through publications, trade missions, participation in space sector trade events, and an information service on current and future business opportunities. It also conducts and publishes market reports and surveys.

GDTA conducts training in remote sensing, distributes satellite data, performs value added data processing and interpretation, and carries out airborne surveys.

Satel-Conseil is an international satellite telecommunications consulting firm, which works closely with French industry in pursuing world market opportunities for space and ground segments.

Spot Image has been formed to carry out the commercial exploitation of the SPOT system through sale of data and value-added products.

Intespace, the newest CNES offshoot, offers environmental test services and facilities for development, qualification and acceptance testing, together with related engineering, design, training and consultant services.

Given the current controversy in the United States over the proposed commercialization of land remote sensing services, the case of Spot Image may deserve a closer review. The SPOT program is divided into two discrete responsibilities -- satellite development, launch and operation are the responsibility of CNES, while Spot Image is responsible for data processing, marketing and distribution on a commercial basis. CNES will provide direct readout services to Spot Image-operated stations, as well as to foreign facilities that have operating agreements with Spot Image/CNES.

CNES holds 39 percent of Spot Image, while Matra (SPOT spacecraft prime contractor) and SEP (the major French spacecraft propulsion firm that also specializes in SPOT/Landsat data reception and processing equipment) each hold 10 percent.

Reportedly, in the next 10 years Spot Image/CNES hopes to recover through the sale of data products and services an estimated \$300 million in operating, maintenance and satellite replacement costs. The initial \$400 million spent to develop, construct and launch the first satellite and construct the related ground facilities will be written off by the French government as a research and development investment.

The likely key to SPOT's commercial success or failure is the coordinated French government/industry marketing effort, which includes sponsoring SPOT simulation campaigns and workshops, the sale of SPOT/Landsat data receiving and processing equipment and the provision of assistance to developing countries for land remote sensing activities.

Since 1980, GDTA has been conducting simulation missions worldwide to acquaint potential users with SPOT data well in advance of the launch of the first satellite. In concert with these activities and with CNES authorization, SEP has been aggressively marketing SPOT/Landsat ground system hardware and data processing equipment, often with French government financing assistance. Spot Image estimates that approximately 20 facilities worldwide will be receiving SPOT data by 1986.

CNES's Centre de Rectification des Images Spatiales (CRIS) will be responsible for archiving raw SPOT data and producing standard image products. Based on customer requests, Spot Image will order from CRIS the required data which will be reproduced and processed to order. Spot-Image will also maintain a central catalog of data archived and available through both CRIS and foreign ground stations. Under joint agreement with Spot Image and CNES, foreign ground station operators will be granted exclusive rights to receive, process, archive and distribute SPOT data within "zones of commercialization" defined in the agreements. Customers outside these zones, or whose requests are not met by the relevant ground station operator, may order data from Spot-Image. Data will be made available to users on a non-discriminatory basis.

CNES/Spot Image are to receive revenue both from sale of data and from direct readout to foreign ground stations. Under current plans, three separate fees will be charged to foreign ground station operators -- a subscription fee, giving the customer the right to receive SPOT data; a basic program fee, covering a base amount of data to be transmitted from SPOT to the ground station; and a fee for any data request not within the basic program. To protect its commercial rights to SPOT data, CNES/Spot Image have claimed ownership of all copyright interests in SPOT data, regardless of the form in which they are transmitted or used. To date, the claim that SPOT data are copyrightable has only been supported under French law; enforceability in U.S. courts remains to be established.



## THE EUROPEAN SPACE AGENCY (ESA)

Much of ESA's role in the commercialization of space has already been discussed in the context of the French and German national programs. By pooling the resources of its member states and allocating industrial participation in its projects on the basis of their contributions, ESA has contributed greatly to the development of space industrial capabilities in Europe. Moreover, its multinational character has provided a matrix for the development of multinational enterprises such as Arianespace, EUMETSAT and EUTELSAT.

### Budget Levels and Budget Priorities

The ESA budget largely mirrors and complements those of member state national programs. Some 36 percent of ESA's budget was provided by France and the Federal Republic of Germany in 1982, and this "double-counting" must be taken into account in assessing Europe's total investment in space. The following table gives a sense of the distribution of these funds over time.

Table 5.

#### ESA Budget Summary (in millions of Accounting Units)\*

<u>Line Item</u>	<u>1979</u>	<u>1980</u>	<u>1981</u>	<u>1982</u>
General budget	78.7	75.3	137.7	153.1
Science program	85.5	88.4	95.4	100.4
Earthnet	6.8	4.6	14.8	5.6
Other mandatory programs	37.0	10.3	----	----
Earth observation	36.6	36.2	29.0	35.4
Telecommunications	96.5	124.2	202.7	183.5
Spacelab	136.4	125.5	67.9	63.6
Ariane	159.1	161.1	214.5	134.7

\* Figures derived by reconvertng US\$ figures using official exchange rates. May differ slightly from original ESA figures due to rounding errors.

A. EUTELSAT -- Other than Arianespace, the most significant regional commercialization initiative in Europe, reflecting the transfer of ESA assets to an operational mode, is EUTELSAT. Originally formed under an interim arrangement in 1977, EUTELSAT's Definitive Agreements were signed early in 1983 following negotiations among 24 European countries in mid-1982.

EUTELSAT's largest stockholders are the telecommunications administrations of France, the United Kingdom, Italy and the Federal Republic of Germany. Share allocations are based on projected traffic. Membership on an essentially commercial basis is open to all European countries whose telecommunications administrations are members of the European Council on Posts and Telecommunications (CEPT).

Using the ECS satellites developed by ESA, EUTELSAT will provide government telecommunications services and commercial services, including communications and television program distribution.

B. EUMETSAT -- In March 1983, the 17-nation Intergovernmental Conference on an Operational European Meteorological Programme reached agreement on a 12-year program for European meteorological services. The program established EUMETSAT as the future governing organization for European meteorological satellite services, and authorized ESA, acting in its behalf, to implement a program valued at 400 million AU (US\$ 390M). The program includes:

- procurement of three operational geostationary meteorological satellites, improved versions of ESA's Meteosat;

- Ariane launch services for the three satellites in May 1987, August 1988 and November 1990;

- continued operation of Meteosat until launch of the first operational spacecraft; and

- operation of the three improved spacecraft until the end of the program in November 1995.

#### CANADA

To a greater degree than those of any other country in this review, Canada's space activities are decentralized. Canadian space program elements are scattered among ten

government departments. In 1980, primary responsibility for coordination of these activities, carried out through an Interdepartmental Committee on Space (ICS) was shifted from the Ministry of Communications to the Ministry of State for Science and Technology. Other primary participants in civil space programs with commercial implications are:

- the Department of Communications, responsible for satellite communications

- the National Research Council of Canada, responsible for basic scientific and technological research

- the Department of Energy, Mines and Resources, which conducts research in remote sensing technology and applications

- the Department of Fisheries and Environment, responsible for environmental remote sensing; and

- the Department of Industry, Trade and Commerce, which promotes the development of the Canadian space, electronics and computer industries.

The Canadian program is conditioned by two main thrusts: a focus on satellite telecommunications and remote sensing, areas of activity which meet specific needs resulting from Canada's unique geography and demographics; and an emphasis on developing independent industrial capabilities, flowing from both economic interests and broader Canadian political-economic policies.

A 1968 Canadian government white paper on satellite communications concluded that "a domestic satellite system of even a few channels would make television service in both French and English available to any point in Canada ... sooner, and at a lower cost, than would any other known system of communication."

Given Canadian geography and the sparseness of population over much of its territory, remote sensing, both for environmental monitoring and for resource identification and management, has received considerable emphasis. Canadian efforts have focused particularly on the ground segment, from the standpoint of research interest and as an area in which Canadian industry has developed highly competitive capabilities in world markets.

The role of space in Canadian industrial development is perhaps the most striking element of Canadian space commercialization policy. Telesat Canada and SPAR Aerospace,

in particular, have achieved a high level of independent capability and competitiveness on world markets. This has been the result of a conscious policy, based on the judgment that a domestic space industry could not only meet Canada's requirements for space systems more economically than imports but could also generate significant export earnings and spin-off benefits, both in terms of technological inputs to Canadian industry and as an enhanced image for Canadian non-space products at home and abroad.

### Budget Levels and Budget Priority

In December 1981, Canada increased its space budget by one-third to C\$476 million, to be spent over the next four years in the following program areas:

Communications	C\$103.6 M
Remote sensing	135.7 M
Space science	72.9 M
Technology development	156.1 M

Spending over time (actual and proposed) is given in Table 6.

Table 6.

#### Canada - Total space program expenditures (C\$ millions)

<u>Activity</u>	<u>81/82</u>	<u>82/83</u>	<u>83/84</u>	<u>84/85</u>
Communications	22.8	29.3	32.8	18.7
Remote sensing	26.3	42.2	35.4	31.8
Space science	11.8	19.1	21.1	20.9
Technology development	34.1	44.5	44.8	32.7
ESA relationship	1.7	1.8	1.9	2.1
TOTALS	96.7	136.9	136.0	106.2

### Space Commercialization Priorities and Efforts

The Canadian space program is notable for a particularly explicit inclusion, under the goals of individual projects, of industrial/commercial objectives.

A. Satellite broadcasting and communications -- Canada became the first nation to operate a domestic satellite communications system in January 1973 with the commissioning of Anik-A. Anik-B, in 1978, added Ku-band capabilities, which were leased

to the Canadian government for follow-on experiments after the end of the CTS/Hermes project. The first Anik-C and -D satellites were launched in 1982, bringing, respectively, operational Ku-band capabilities and greatly increased C-band capacity to the Telesat system.

Telesat Canada, which owns and operates the Aniks and their associated ground segment, is owned jointly by the Canadian government and the major Canadian telecommunications carriers. The Anik-A through C satellites were procured from Hughes Aircraft, with growing participation by SPAR Aerospace, while SPAR was the prime contractor for Anik-D. The imported content of Anik-A was about 87 percent, but the import content of the Anik-D's will be under 50 percent. In 1982, SPAR won its first international satellite competition to supply two satellites for Brazil's domestic satellite system. Although Hughes is a significant subcontractor, the Canadian share of the Brazilsat contract is about 60 percent.

In addition to domestic communications satellite activity, another significant thrust of Canada's communications satellite activities with great commercial implications is the M-sat program. Intended to provide exurban land mobile communications compatible with existing and planned cellular radio-telephone systems, M-sat began life as a planned government-funded experimental system proposed for development on a cooperative basis between the United States and Canada. This plan was overtaken by rising private-sector interest in providing this service, however, and in November 1983 a Memorandum of Agreement was signed between NASA and the Canadian Department of Communications (DOC) providing for a leading role by private industry in the two countries in supplying orbital capacity to meet the two agencies' needs, while also making capacity available for commercial sale. The eventual market for ground equipment for land mobile satellite service is projected in the billions of dollars, once the orbital capability becomes available. Both agencies are developing plans to engage specific industry participation, and are also awaiting frequency allocations from their governments.

A specialized adjunct of satellite communications is the Search and Rescue Satellite system (SARSAT), in which Canada participates along with the United States and France (the USSR provides a compatible, interoperable system called COSPAS). While the system uses existing emergency beacon transmitters to determine the position of aircraft and ships in distress, a 406-MHz evolution of the system, providing additional data and improved precision to rescuers, may open up a new ground sector market.

In another significant thrust, Canada has also joined ESA's L-Sat program, which is developing a large multipurpose

communications platform to provide FSS and DBS services at Ku-band, a Ka-band payload, and propagation research beacons at 12, 20 and 30 GHz. In exchange for its financial contribution, which accounts for a large part of the increase in the technology development line of the 1981 - 1985 Canadian budget, Canada will supply the solar array for L-Sat, and will support the prime contractor, British Aerospace Ltd., in spacecraft integration and test, using the facilities of DOC's David Florida Laboratory for spacecraft environmental testing.

B. Remote sensing -- As mentioned elsewhere, Canada was an early participant in the Landsat program, and currently operates two ground stations for direct reception of Landsat data. In part as a result of this early start, a Canadian firm is now among the leading contenders in the market for Landsat ground equipment and for upgrades of existing Landsat stations to receive higher-resolution Thematic Mapper data.

As a consequence of its interest in synthetic aperture radar for ice and ocean monitoring, Canada has identified a requirement for an active remote sensing satellite called RADARSAT. The Canadians define the project objectives specifically to include the development of industrial competence in SAR technology; technology development work is underway. Canada is also participating in development of ESA's first remote sensing satellite, ERS-1, scheduled for launch in late 1987. Its share of the ERS-1 effort is in SAR technology development, which will contribute directly to the Radarsat project.

#### Government - Industry Relations and Space Commercialization

Although Canadian space technology procurements are not limited to Canadian industry, an independent study predicts that Canadian industry will likely continue to receive first-round preferential treatment, as it did in the procurement of Anik-D, the first to be won by a Canadian prime contractor. Accordingly, the next generation of Aniks-- three E-types (Ku-band) and two F-types (C-band)-- is likely to be built by Canadian industry.

In addition to its role in Telesat Canada, the Canadian Government also owns 97 percent of SPAR Aerospace, the principal Canadian spacecraft manufacturer and maker of the STS Remote Manipulator System (or CANADARM).

#### JAPAN

Japan's National Space Development Agency (NASDA) was established in 1969 as a "special corporate entity" charged with prime responsibility for implementing "practical applications of space developments." Under this charter, NASDA divides its activities into five basic areas -- Earth

observation, communications and broadcasting, space transportation, space experiments, and basic technology. Interestingly Japan's First Materials Processing Test, a Spacelab payload scheduled for flight aboard the Space Shuttle in 1988, is carried under the space experiment heading, a classification which apparently reflects perception of the mission as a basic scientific investigation rather than an activity with near-term commercial implications.

### Budget Levels and Budget Priorities

As indicated in Table 1 above, the overall Japanese space budget has remained essentially level in real terms since 1979, and in the last several years has declined in constant terms. The same is also true of NASDA's budget, which falls under the Japanese government's Science and Technology Agency.

The following table gives a sense of Japanese space budget priorities among the principal agencies involved.

Table 7.

<u>Allocation of Japan's Space Budget (billions of Yen)*</u>			
<u>Agency</u>	<u>JFY82</u>	<u>JFY83</u>	<u>JFY84</u>
STA (NASDA)	87.66	87.43	85.74
Min. of Education (Space Sci.)#	12.92	15.18	NA
Min. of Transportation (Metsat operations)	4.54	7.06	NA
Min. of Posts/Telecomm. (DBS, FSS)	1.94	1.59	NA
Min. of Intl. Trade and Industry (remote sensing)	1.40	1.47	NA

\* Figures in this table were reconverted from a US\$ table. Figures may differ slightly from original Yen amounts due to rounding errors.

# Budget for the Institute of Space and Astronautical Sciences (ISAS)

The following table gives a breakdown of NASDA's JFY 83 and 84 budget plan.

Table 8.

The Japanese Space Applications Budget (in billions of Yen)\*

<u>Line item</u>	<u>JFY83</u>	<u>JFY84</u>
H-1 launch vehicle	24.47	30.87
BS-2 DBS satellite	6.485	6.742
GMS-3 geostationary metsat	5.086	0.895
MOS-1 marine observation satellite	11.962	11.052
ETS-V engineering test satellite	0.733	2.138
CS-3 domestic communications sat.	0.516	4.062
BS-3 DBS satellite	0.020	0.430
FMPT (Spacelab mission)	1.186	1.687
ERS-1 land observation satellite	1.795	0.854
Large rocket (studies)	0.556	1.347
U.S. space station studies	0.069	0.080

\* This breakdown covers only the STA budget under which NASDA is funded; details of other government agency budgets for space applications in 1984 are not yet available, but in 1983 amounted to less than 18 percent of the total. For comparison purposes, an exchange rate of 230 yen/US\$1.00 may be assumed.

Space Commercialization Priorities and Efforts

Since its inception, the Japanese space program has emphasized several parallel themes:

-- the development of a Japanese satellite launch capability, initially through the importation of technology but eventually through the maturation of a domestic technological base;

-- the development of meteorological, communications and direct broadcast satellites through teaming between Japanese and U.S. satellite manufacturers, with a gradually increasing Japanese share of the effort leading eventually to an independent Japanese industrial capacity.

-- development of remote sensing technologies, leading eventually to a commercializable program; and

-- basic experimentation in materials processing, zero-G life sciences and space technology.

A. Launch Vehicles -- From its beginnings, NASDA's launch vehicle program has been designed for a gradual transition from reliance on imported hardware and technology to entirely indigenous content. NASDA's first launch vehicle was the



three-stage N-I, based on Thor Delta hardware and technology with an indigenously-developed second stage engine and capable of placing approximately 130 kg. in geostationary orbit. Seven satellites were launched with the N-I from 1975 through 1982. Development of the N-II vehicle began in 1974; although still derived from U.S. Delta technology, the N-II uses domestic versions of the N-I's first stage engine with nine solid strap-ons, both manufactured in Japan. The second stage engine is an upgraded Delta second stage, as is the third stage solid motor, purchased from the United States. The Digital Inertial Guidance System of the N-II was also developed in the United States. There have been five successful N-II launches to date, with another three scheduled by the end of 1986.

Meanwhile, the H-I vehicle, begun in 1975, is expected to become NASDA's main launch vehicle for the last half of the 80's. The Delta-derived vehicle is designed to be capable of delivering 550 kg. to geostationary orbit. The first stage engine will be the same as the N-II, with the domestically-developed LE-5 cryogenic engine in the second stage and a domestically-developed solid third stage motor. Guidance will be provided by a NASDA-developed system. A two-stage test is scheduled for early 1986 and a full-scale test flight by early 1987. In July 1983, the Special Committee for Long-Range Vision of the Space Activities Commission submitted its report to the Commission on directions for the Japanese space program through the remainder of the century. Central in the Committee's recommendations was an ambitious call for the development of the next-generation H-II as a completely indigenous system capable of placing 2000 kg. in geostationary orbit by the early 1990s. Four different candidate configurations were discussed, with both first and second stages fueled by liquid hydrogen and oxygen. The report urges this development, and particularly the completely indigenous design, as a basis for entering the world launch services market, an option presently denied because of governmental agreements with the United States under which Delta technology has been transferred, as well as by the limited payload capability and high unit cost of the current Japanese vehicles.

The total cost of the H-II development is estimated at something comparable to the development of Ariane, or over 1983 US\$ 1 billion. It is not reflected in the 1984 NASDA budget summarized above, because the recommendations of the Committee are reportedly still under review, for incorporation in revised space development guidelines to be formulated and released next year. It is not clear how and when it will appear, given conflicting priorities and apparently limited resources available to the Japanese program.

B. Communications and broadcasting satellites -- Since its beginnings in 1972, the Japanese communications satellite program has followed lines somewhat parallel to the launch

vehicle program, including extensive early procurements of foreign technology and an intended transition to entirely indigenous capabilities. A similar pattern has marked the direct broadcast satellite program which began in 1973.

The two spacecraft programs have been conducted in parallel with Japanese prime contractors supported by U.S. spacecraft manufacturers. Mitsubishi Electric Company has been given responsibility for the CS communications satellites (CS-2, CS-2a and CS-2b are currently on orbit, providing C-band and experimental Ka-band service, the first use of the latter band on a spacecraft), with major and slowly-declining technical assistance from Ford Aerospace. The BS series of direct broadcast satellites (the first operational Ku-band DBS satellite, BS-2a, was launched in January 1984), is built by Toshiba with similar assistance from General Electric. Follow-on satellites in each series, sized to fit the H-I vehicle, are scheduled for 1989 and 1990 launch. The Long-Range Vision report recommends large CS-4 and BS-4 satellites to utilize the proposed H-II large launch vehicle. While it is not clear that Japanese industry will be able to meet these objectives with entirely indigenous technology, the Japanese government has emphasized that its fundamental policy requires that these large satellites be procured from domestic contractors.

C. Remote sensing -- NASDA has been operating a Landsat ground station since January 1979, providing coverage of Japan, northeast China, and Korea. In addition, Japan plans an ambitious program of ocean and land remote sensing satellites for the remainder of this decade. The series includes:

Marine Observation Satellite-1 (MOS-1): 1986 launch to sun-synchronous polar orbit. Multi-spectral CCD radiometer (50m. resolution), visible/thermal IR radiometer, microwave scanning radiometer.

Earth Resources Satellite-1 (ERS-1): 1990 launch proposed to sun-synchronous polar orbit. Design studies began in 1982 and prototyping of instruments is underway. In addition to visible and near-infrared radiometers, primary instrument is to be an L-band synthetic aperture radar, with target resolution of 25 m. x 25 m. over a 75 km. swath width.

Japan has not yet announced any plans for dissemination of data from these satellites beyond experimental evaluation by research institutes and academic institutions. Commercialization seems likely, however, and perhaps as soon as ERS-1; in a recent publication NASDA obliquely stated:

In the future, the results accumulated with ETS-III [an engineering satellite to evaluate high-power solar arrays, three-axis stabilization systems and active thermal control] and MOS-1, etc., will establish technical expertise that can be exploited in the development of an earth resources observation system. Active cooperation is being sought from domestic manufacturers, national experimental research institutions, and universities...

D. Materials processing and zero-G life sciences -- Since 1979, NASDA has been preparing for the First Materials Processing Test (FMPT), scheduled for early 1988 aboard Spacelab. The name aside, the mission's three-double-rack complement of experiments will include materials processing, life sciences and space technology experiments. Approximately thirty proposals from Japanese research institutes, universities and other institutions have been selected from over 100 submittals.

NASDA has also been conducting materials processing experiments on sounding rockets (six experiments since 1980), and some of the experiments performed have led to follow-on activities planned during FMPT. It is perhaps indicative of NASDA's judgment on the relative maturity of space materials processing that the FMPT mission has slipped from an originally proposed date of 1986 to its present schedule.

E. Technology development -- NASDA freely acknowledges its technological debt to foreign programs, notably that of the United States. At the same time, as mentioned above, Japan intends to reach independence and eventual parity in key space technologies. The ETS series of satellites has been produced domestically with this objective in mind. ETS-V, currently in the design phase and scheduled for launch in 1987 on the H-I full-scale test flight, is intended to establish Japanese understanding of the technologies required for large three-axis stabilized spacecraft, and to conduct mobile satellite communications, navigation and search-and-rescue experiments (with aircraft, with ships and between ships).

#### Government-Industry Relations and Space Commercialization

The extraordinarily close Japanese government - industry relationship has already been characterized above, both in general and in specific space program contexts. The allocation of government resources to space activities with commercialization potential suggests that this area enjoys a fairly high priority in Japanese economic planning. Investments have not been comparable, however, to those in the computer and terrestrial electronic industries. And, as mentioned above, the Japanese government's response to the ambitious recommendations of the Long-Range Vision report remains to be seen.

## CONCLUSION

This survey has not attempted to argue any particular thesis on the directions being taken in space commercialization in the countries reviewed. Nevertheless, it may be useful in conclusion to attempt a few observations about the similarities and differences among the various programs.

All of the national programs surveyed count development of their domestic aerospace industry capabilities as an important motivation for conducting space activities. They see the benefit in terms of import substitution and export earnings, opening markets which until recently were the exclusive preserve of U.S. manufacturers, and in tangible and intangible spin-offs to terrestrial pursuits. Heightened national prestige and a bolstered reputation for high technology, adding luster to more prosaic products, are often-cited benefits from an active space program.

Budgets in all of the programs surveyed are small by comparison with the United States space budget, and their focuses are correspondingly narrower and more specialized. Most have felt, to some degree, the effects of the recent worldwide recession, but are now in a renewed growth phase.

While they vary widely in their budgetary allocations to materials science, none of these foreign programs is making the sort of investments to indicate that a major industrial push has begun. The Japanese and especially the German governments are prepared to make a substantial investment in basic scientific research in materials processing, against the day when commercial prospects emerge, but their industry apparently has not yet been persuaded of near-term profit potential worth investing significant amounts of private capital.

On the other hand, France and Japan are making major launch vehicle investments, determined to compete for the world markets for launch services, and all are investing substantially in communications satellite development.

To sum up, thinking on space commercialization in other countries, at least as reflected in their program plans and decisions, appears to be running generally parallel with that in the United States. As they see it, a few fields are here today, but the promise of most remains more tantalizing than real. The next decade or two will tell how much of the promise will be realized, and by whom.

# LEGAL CONSIDERATIONS AND COOPERATIVE OPPORTUNITIES FOR SPACE COMMERCIAL ACTIVITIES

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## ABSTRACT

It is a national policy to make the capabilities of the Space Transportation System available to a wide range of potential users. This includes its availability as a space manufacturing facility for commercial activities, which may be carried out on a reimbursable basis or as a joint endeavor with NASA, but with substantial private investment. In any high risk, long lead-time research and development activity directed towards commercialization, the protection afforded the results of the research and development under the laws relating to intellectual property rights may provide an important incentive for private investment.

The paper reviews NASA's policies and practices for the protection of privately-established intellectual property rights involved in STS use, with particular emphasis on reimbursable launch agreements and joint endeavor agreements.

## INTRODUCTION

The Space Transportation System (STS)<sup>1</sup> has reached a point in its operational maturity where it can be treated as a national resource. That is, it can be made available to a variety of customers, public and private, for a wide range of uses in space not previously available. These potential uses greatly exceed the capabilities of expendable launch vehicles, which are limited primarily to placing free-flying payloads into orbit. While this capability still exists, the STS is, in addition, a true spaceborne laboratory or facility for the conduct of experiments, demonstrations, and even ongoing commercial operations for space manufacturing. In recognition of this, NASA has evolved policies whereby the STS may be made available to all potential customers under a broad range of agreements or arrangements. These possibilities range from use by NASA<sup>2</sup> and other Government agencies to carry out their traditional programs and missions,<sup>3</sup> to use by the private sector for commercial purposes on a reimbursable basis.<sup>4</sup> However, NASA has recognized that for commercial uses other than for launches of free-flying payloads of the type normally launched by expendable launch vehicles (e.g., communications satellites), the risks and uncertainties, both technical and financial, are not necessarily conducive to early commitment of private resources. Activities such as space manufacturing, for example, involve a number of risks not present in earlier commercial launches. Thus, intermediate possibilities for risk-sharing, falling between full Government funding on one end of the funding spectrum and full reimbursement on the other end of the funding spectrum, had to be considered in order to provide an additional inducement to encourage commercial organizations to take the first "small step" towards manufacture in space. This led to the development, by NASA, of the joint

endeavor approach to bridge the gap between traditional Government funding and full private funding in order to demonstrate the commercial viability of STS use in certain technological areas. Basically, a joint endeavor is a cooperative arrangement between NASA and a private participant to share the risks of a common objective of demonstrating commercial feasibility for a given spaceborne activity, with each party funding its own agreed-upon program responsibilities to reach that objective.<sup>5</sup> Not surprisingly, since one of the unique capabilities of the STS is to provide a facility for experiments and demonstrations in a zero-gravity, near-perfect vacuum environment, the first joint endeavors entered into were for material processing in space.<sup>6</sup>

## INCENTIVES FOR COMMERCIALIZATION

Even though the policies, implementing mechanisms and legal instruments have been developed to enable use of the STS under a variety of funding possibilities, including risk-sharing under a joint endeavor, these factors alone will not necessarily result in private investment for commercial use. Much has been written and many theories expounded, ranging from tax incentives to interest rates, and from regulatory reform to corporate management practices, on the economic, competitive, and political factors that must be present to create an environment conducive to substantial private investment for undertaking high-risk, long lead-time research, development and demonstration activities for the marketing of commercial products and processes. While these factors are not limited to commercialization in space, the risks and lead times involved in space activities introduce even greater uncertainties. However, one factor that appears to be relatively constant in any high-risk, long lead-time research and development activity directed towards commercialization, whatever the other variables, is the need for some protection that provides a degree of exclusivity as an aid in assuring a return on the investment, and to minimize predatory, second-to-market practices. While the need for this exclusivity may differ depending on the nature of the technology and the various economic and competitive factors involved, it is usually a truism that in most situations the higher the risk or the longer the lead time, the greater the exclusivity needed as an incentive for a significant private commitment of funds.

From a legal point of view, this exclusivity may be established by the protection afforded under the laws relating to intellectual property rights. These rights manifest themselves in three basic ways: patent protection, copyright protection and trade secret protection.<sup>7</sup> It was therefore not unexpected that during the evolution of NASA's policies to encourage the commercial use of the STS, whether such use be on a reimbursable basis or under a joint endeavor, there were recurring concerns expressed by the private sector over the manner in which NASA would treat the rights to inventions, patents, trade secrets, and to some extent copyright, involved in such activities.

What follows is a discussion of NASA's policies and practices regarding the protection of privately-established, intellectual property rights as they may relate to commercial activities in space, such as space manufacturing. The discussion focuses on current policies and practices in these areas under both reimbursable launch agreements and joint endeavors agreements.<sup>8</sup>

## RIGHTS TO INVENTIONS AND PATENTS

### Reimbursable Launches

It is NASA policy not to acquire rights to any inventions or patents which may be used in or result from an STS launch and associated services for which NASA is reimbursed.<sup>9</sup> This is a straightforward policy which requires no implementing action other than a statement to that effect in the launch agreement. The rationale for this policy is equally straightforward; that is, since the launch and related services are performed for the customer, and not for NASA, and since NASA is reimbursed for such services, neither NASA's statutory provisions regarding patent rights nor the Presidential Memorandum on Government Patent Policy apply.<sup>10</sup> This is a long-standing NASA policy for reimbursable launches on expendable launch vehicles that has merely been formalized in policy directives relating to STS, as well as in the standard launch service agreement for STS, to avoid any misunderstanding that may inhibit the use of STS on a reimbursable basis.

### Joint Endeavors

NASA's policy regarding inventions and patents resulting from a joint endeavor differs somewhat from the policy for reimbursable activities because of the mutual interests involved. It is important to note, however, that as in the case of reimbursable activities, neither NASA's statutory patent provisions nor the Presidential Memorandum apply to the activities of the non-NASA participant under a joint endeavor. This is because a joint endeavor, also, does not require the performance of work for NASA. Rather each party carries out certain stated responsibilities on its own behalf, and funds its own activities, in furtherance of a common, mutually agreed-upon objective. Thus agreement on the treatment of rights to inventions and patents must be stated in the joint endeavor agreement. This usually requires negotiation to reach a mutually acceptable approach consistent with the purposes of the particular activity involved.<sup>11</sup> As a basic premise, since the common objective upon which a joint endeavor is based is the encouragement of early space ventures to demonstrate usefulness of space technology to meet marketplace needs, the commercial participant may retain all right, title and interest to any inventions and resulting patents, but NASA obtains certain contingent rights consistent with that objective. Essentially these contingent rights are structured to assure limited access to, or availability of, the technology for further commercialization under agreed-upon terms and conditions in the event the private participant cannot or does not carry out its responsibilities under the joint endeavor. Additional consideration may be given to availability sufficient to meet public needs in the area of health and safety if applicable, as well as an understanding on the allocation of rights between the parties in the event of termination by either party under various circumstances.

While these contingent rights are a matter of negotiation depending on the technology involved and the respective responsibilities of each party, in the typical agreement involving the demonstration of the feasibility of a space manufacturing process, NASA may receive a royalty-free license for certain stated Governmental purposes, as well as the right to license others upon reasonable terms and conditions in the event the private participant has not, or cannot be reasonably expected to take, effective steps to achieve commercialization, or if the private participant unilaterally terminates in some situations. If the involved technology is the type that could directly affect the public health or safety, the contingent rights may be expanded to

assure that such technology is reasonably available to meet those needs. Early termination will usually leave all rights with the private participant, except that the parties may mutually agree to negotiate allocation of rights. Somewhat greater contingent rights may be expected by NASA if there is unilateral termination after certain launch commitments are made. In all instances, these contingent rights will not become effective unless an express determination is made by the NASA Administrator, or designee, as to the need to exercise the right. In making such determination the private party is given notice, an opportunity to present facts and reasons why it should not be made, the opportunity for an administrative hearing within NASA, and the right to seek legal redress, before the determination becomes final and acted upon.

## RIGHTS TO DATA, INCLUDING TRADE SECRETS AND COPYRIGHTS

Protection of valuable information such as design, manufacturing and processing information (know-how), as well as certain commercial and financial information, whether this information is patentable or not, is also an important consideration in any commercially-oriented enterprise. Such information, when reduced to tangible and useful documented form (on any media) is commonly referred to as "data." Of necessity NASA must receive or have access to some of this data in order to carry out its responsibilities under either a reimbursable launch agreement or a joint endeavor.

### Reimbursable Launches

Data is acquired from a customer under a reimbursable launch agreement only to the extent necessary to enable NASA to carry out its responsibilities under the agreement. Generally this is data necessary for payload integration, establishment of launch parameters, safety checks, determination of orbital performance, verification of peaceful purposes and compliance with law, and related matters. Much of this data, while generally technical in nature, is not of the type that would qualify for protection as a trade secret (i.e., it is form, fit and function data, data readily apparent by inspection, or data which the customer either has not maintained, or does not wish to maintain in confidence or protect as a trade secret). Thus the expectation (and intent) is that most of the data furnished to NASA in order to carry out a reimbursable launch will be provided without restriction.

However, there may be instances where some of the data furnished under a reimbursable launch agreement may qualify as a trade secret which the customer wishes to protect from unauthorized use and disclosure in order to maintain its trade secret status. In this event, as is the case with inventions and patents, the statement of NASA's policy regarding such data is straight-forward.<sup>1 2</sup> However, implementation of this policy requires further, positive action. For example, it is necessary in the launch agreement to create an understanding as to the type of data to be protected, as well as an understanding that in order for protection to be established and maintained such data is to be treated in confidence, with specified limitations on its use, duplication and disclosure.

This is achieved by provisions in the launch agreement authorizing the customer to place a restrictive legend on any technical data (such as detailed design, manufacturing and processing information) that the customer considers a trade secret in order to put NASA on notice that the data is to be protected. The legal effect of acceptance of qualifying data with the authorized notice is to obligate NASA to limit the use, duplication and disclosure of the data to the



purposes stated in the notice; that is, those purposes necessary for NASA to carry out its launch responsibilities. Disclosure of the data may extend to NASA contractors, but only to the extent necessary to support the launch and only if the support contractor has agreed in writing to protect the data from further use, duplication or disclosure. This maintains the chain of confidentiality necessary for trade secret protection.<sup>13</sup>

Obviously, the submission of restrictively-marked data creates administrative burdens, as well as certain legal risks, for both NASA and the customer. Thus it is NASA policy to include provisions in the launch agreement requiring that, before delivering restrictively-marked data, the customer must inform NASA that the data is considered a trade secret, and not to deliver it unless there is a written request for delivery by NASA. This provides a checkpoint to prevent the over-ordering of restrictively-marked data by NASA and to reduce over-marking of data by the customer.

A somewhat different approach is taken for a customer's financial and commercial data if data of that nature is to be furnished under a reimbursable launch agreement. This difference is based on an assumption that very little, if any, data of that type will be required to carry out a launch, as well as an assessment that the law regarding protection of non-technical data (at least in dealings with the Government) is less clear than as it is regarding the protection of technical data qualifying as a trade secret. Basically, as to non-technical data, NASA agrees that if such data is considered confidential or privileged, and if its disclosure could either cause substantial harm or impair NASA's ability to obtain such data in the future, NASA will protect such data to the extent permitted by law.<sup>14</sup>

### Joint Endeavors

While the same basic tenets discussed above apply to data furnished to NASA by the participant under a joint endeavor, some modifications are made in recognition of the common objective of both parties to achieve commercialization of the results of the involved activities. Also, of necessity, the rights and obligations of the parties under a joint endeavor are considered on a case-by-case basis, taking into account the specific technology involved, the respective responsibilities of both parties, and the interrelation of intellectual property rights to the technology and the objectives to be achieved. As a general rule, in the area of space manufacturing, NASA will agree to treat most of the data developed or used by the other participant and required to be furnished to NASA in carrying out its responsibilities under a joint endeavor as a trade secret and to restrict or limit its use, duplication and disclosure to only those activities necessary for NASA to carry out its concomitant responsibilities under the joint endeavor. Again, as in the case of a reimbursable launch, the intent is that the amount of such data to be furnished to NASA be kept to a minimum. In addition, in recognition of the mutual objectives of both parties, as well as the diversity of the nature of the activities, there is a greater need in a joint endeavor to have a clear understanding as to certain data which NASA is to obtain without restriction and may be released to the general public. Thus a joint endeavor will usually include certain agreed-to categories of releasable information.<sup>15</sup>

Once the basic approach mentioned above has been established, the major point of departure between the treatment of data rights under a joint endeavor and under a reimbursable agreement is in the area of contingent rights. Essentially such contingent rights regarding data are structured to be compatible with the contingent rights acquired in relation to inventions and patents. That is, the participant to a joint endeavor agrees to provide sufficient data, and

attendant rights to either NASA or third parties, in those limited situations where the participant is not pursuing the commercialization objectives of the joint endeavor, fails to perform, unilaterally terminates under certain circumstances, or as may be needed to practice license rights acquired under patents and inventions. As is the case with inventions and patents, this may be under reasonable terms and conditions, as well as under protective conditions so as not to compromise the intellectual property rights in the data. Also, the same procedural safeguards apply to a determination to exercise contingent rights in relation to data as apply to the contingent rights for patents and inventions.

## COPYRIGHT CONSIDERATIONS

As a general rule, copyright matters have not been a consideration, and are not expressly addressed, in a reimbursable launch agreement or a joint endeavor agreement relating to space manufacturing. This comes about primarily because of the nature of the activities, where it is customer preference to protect its technology as a trade secret rather than to publish under copyright.

Under the copyright laws, right to establish claim to copyright in a work resides in the author unless there is an express understanding otherwise, or unless the work is prepared by an employee within the scope of employment. Thus silence on the matter in a reimbursable launch agreement or a joint endeavor agreement means that the right to establish claim to copyright stays with the customer or participant and does not flow to NASA or the Government. There is one very limited exception in that to the extent copyrighted material may be furnished to NASA under the agreement, NASA has an implied license to duplicate material to the extent necessary to carry out its responsibilities under the agreement.

If the situation should arise (outside the realm of space manufacturing) where the production of copyrightable works may be an objective of a joint endeavor, the allocation of copyrights is a matter of negotiation. Generally, the principles discussed in conjunction with patents and trade secrets would apply; that is, commercial rights will be left with the private participant, with NASA receiving certain contingent rights, license rights, or derivative rights as appropriate and consistent with the mutual objectives of both parties.

## CONCLUSION

NASA takes the view that the development of its policies, practices and procedures in the area of intellectual property rights are an integral part of its overall approach to research and development activities in carrying out its mission requirements. Thus during the development of the Space Transportation System, when its potential as a national resource became apparent for a wide variety of customers under diverse funding possibilities, these policies, practices and procedures were continually assessed and refined to provide maximum flexibility to fit the entire spectrum of possibilities. Foremost in this assessment was the recognition of the need to provide an environment conducive to private investment in the furtherance of commercial activities in space, such as space manufacturing. As a result, the policies, practices and procedures discussed above have been developed to provide maximum protection of privately-established intellectual property rights as they relate to commercial activities in space, compatible with NASA's goal of expanding opportunities for U.S. private sector investment and involvement in space activities.

## FOOTNOTES

1. The Space Transportation System for the purposes of this paper, may be considered as consisting of the Shuttle, Spacelab and Inertial Upper Stage and provision for the availability of qualified Atlas/Centaur-class and Delta-class Spinning Solid Upper Stages from a customer.

2. NASA Management Instruction (NMI) 8610.12, Utilization of an Funding for Space Transportation System (STS) Elements and Services for NASA and NASA-Related Payloads.

3. NASA Management Instruction (NMI) 8610.9, Reimbursement for Shuttle Services Provided to Civil U.S. Government Users and Foreign Users Who Have Made Substantial Investment in the STS Program. Published in the Federal Register under Title 14, Chapter V, Subpart 1214.2 (42 FR 8631-8634, February 11, 1977).

4. NASA Management Instruction (NMI) 8610.8, Reimbursement for Shuttle Services Provided to Non-U.S. Government Users. Published in Federal Register under Title 14, Chapter V, Subpart 1214.1 (42 FR 3829-3833, January 21, 1977).

5. Under a typical joint endeavor (relating to materials processing) a private participant selects an experiment and/or technology for feasibility demonstration in space, conducts necessary ground investigations, and develops flight hardware, at its expense. NASA, on its part, provides an STS flight and related support in order to demonstrate feasibility, with the expectation that subsequent to a successful demonstration of feasibility the private participant may become involved in commercial flight operations on a reimbursable basis.

6. NASA's commitment to commercialization in this area is reflected in its announced "Guidelines Regarding Joint Endeavors with U.S. Domestic Concerns in Materials Processing in Space" (44 Fed. Reg. 47,650, 1979), where it is stated: "NASA, by virtue of the National Aeronautics and Space Act of 1958, is directed to contribute to the preservation of the roles of the United States as a leader in aeronautical and space science and technology, and their applications. In furtherance of these objectives, the Administrator of NASA on June 25, 1979, promulgated a statement of NASA Guidelines Regarding Early Usage of Space for Industrial Purposes. These guidelines recognized that 'since substantial portions of the U.S. technological base and motivation reside in the U.S. private sector, NASA will enter into transactions and take necessary and proper actions to achieve the objective of national technological superiority through joint action with United States domestic concerns' ".

7. The laws in the United States relating to patents and copyrights are derived from the U.S. Constitution, Article I, Section 8, and are established by Federal Statutes: Title 35 and Title 17 of the United States Code, respectively. These statutes prescribe certain standards as well as the procedures and formalities to be followed in order to establish and maintain patent or copyright protection. Once a valid patent is established and maintained, protection is afforded against all potential infringers within the United States, including those who may independently develop the invention. Appropriate notice of copyright will preclude all from unauthorized copying. In addition, while the U.S. laws have no extraterritorial effect, similar protection may be established and maintained in most other countries by following and adhering to their standards, procedures, formalities and conventions.

The law of trade secrets, on the other hand, is based on the common law. That is, protection is afforded only to the extent provided by state or local law, and not under Federal statute. A significant distinction between trade secret protection and patent or copyright protection is the element of secrecy or confidentiality, with which the subject matter of a trade

trade secret must be cloaked. In addition, the standards as to the subject matter that may be subject to trade secret protection are more a matter of agreement between the parties than any external standard. Thus if the proprietor of a trade secret is to make it available to another, the subject matter must be identified and made available under an understanding of confidentiality which the other party is aware of and agrees to, or protection may be compromised. Also, trade secret protection is enforceable only against parties who breach this understanding of confidentiality or otherwise acquire the trade secret by improper means, and not against those who may independently or innocently discover it. It is therefore extremely important that in any agreement or arrangement regarding commercially-directed activities relating to space manufacturing (whether they be under a reimbursable launch agreement or a joint endeavor agreement) that the treatment of, and protection to be afforded, trade secrets that are to be made available to NASA be specifically addressed.

8. This is not to suggest that intellectual property rights are not an important consideration in NASA-funded activities. However, NASA's policies and practices in that area are well established and understood, and as a practical matter come into play during the procurement process (see for example, Part 9 of the NASA Procurement Regulation, 41 CFR Ch. 18) and not in consideration of a reimbursable launch or joint endeavor. In order to provide a comparison of the treatment of intellectual property rights arising out of NASA-funded activities with the treatment afforded such rights under reimbursable launch agreements and joint endeavors, the following is a summary of NASA's policies and practices as they relate to NASA-funded activities.

The NASA patent policies for NASA-funded activities, as well as the procedures for implementing those policies, are based on Section 305 of the National Aeronautics and Space Act of 1958 as amended (42 U.S.C. 2457), and to the extent consistent with that Section, the Presidential Memorandum on Government Patent Policy of February 18, 1983. An exception is made for funding agreements with certain small business firms and nonprofit organizations, where NASA follows Public Law 96-517, as implemented by OMB Circular A-124, in the same manner as all other agencies.

Essentially, Section 305(a) of the Space Act provides that any invention conceived or first actually reduced to practice in the performance of any work under any NASA contract becomes the exclusive property of the Government unless the Administrator (of NASA) determines that the interests of the United States will be served by waiving all or any part of the Government's rights under the provisions of Section 305(f) of the Space Act. In making such determinations, NASA's waiver policy adopts the Presidential Memorandum of February 18, 1983, as a guide. Since this Memorandum, in turn, is based on the policy of Public Law 96-517, waivers are liberally granted. A similar result is achieved, albeit by a different procedure, by election of title by a small business firm or nonprofit organization under Public Law 96-517. Any waiver of title granted by NASA, or any election of title by a contractor, is subject to a royalty-free license for Governmental purposes and certain so-called "march-in" rights (as set forth in Public Law 96-517) in order to protect the Government and public interests.

NASA's policies regarding rights to data developed under, or used in, contract performance (including rights to trade secrets based on certain data developed at private expense to the extent such data is used in contract performance), are not covered by express statutory requirements, as are rights to inventions made under contract. There are, however, collateral statutory provisions such as Section 203(a)(3) of the Space Act (42 U.S.C. 2473(a)(3)) and the Freedom of Information Act (5 U.S.C. 552) relating to the public availability of some data involved in or resulting from NASA activities that must be considered in implementing and applying these policies. Thus it is NASA policy normally to acquire data first produced in the performance of a contract without restriction regarding its publication, use or disclosure (i.e., with unlimited rights). It is also NASA policy not to acquire certain "protectible" data

(i.e., trade secrets) unless necessary, but if necessary, to acquire such data under express agreement or understanding not to use or disclose it in a manner that would compromise its value as an intellectual property right (i.e., to acquire it with limited or restricted rights maintaining its confidentiality). Care is taken to agree to protect only that data which can be protected under law (such as the Freedom of Information Act), but once agreed to, maximum protection is assured. However, in order to minimize administrative burdens and legal risks, as an overriding consideration it is NASA policy not to acquire protectible data unless there is a real need for it.

NASA's policies with respect to copyright subsisting in data produced under contract are considered in conjunction with its data policies. As a general rule, permission is required for a contractor to assert or establish claim to copyright subsisting in data first produced under contract. Such permission is usually granted at the time of contracting for scientific and technical articles based on work performed under contract and published in academic or technical journals, and in other situations (except for computer software) is liberally granted upon request.

9. This policy is set forth in paragraph 6(a) of NMI 8610.8 (note 4 supra) and reiterated in the standard reimbursable launch agreement: "6. Patent and Data Rights – (a) NASA will not acquire rights to inventions, patents or a proprietary data privately funded by a user, or arising out of activities for which a user has reimbursed NASA under the policies set forth herein . . ."

10. The policy where the converse is true, that is, where work is performed for NASA and funded by NASA, is discussed in note 8, supra.

11. An extensive discussion which forms a basis for this policy is set forth in a memorandum by NASA's Office of Assistant General Counsel for Patent Matters, entitled "Applicability of Section 305 of the Space Act to Joint Endeavors" (June 19, 1979). This memorandum is part of the record in a Report on Patent Policy, Hearings on S. 1215, Ninety-Sixth Congress, First Session, before the Subcommittee on Science, Technology, and Space, of the Committee on Commerce, Science, and Transportation, United States Senate, July 23 and 27, and October 25, 1979 (Part 1, Serial No. 96-60, pgs. 186-199). In this memorandum a joint endeavor is defined: "A joint endeavor is an arrangement between NASA and a party or parties in which each undertakes to contribute to or participate in a project of mutual benefit, and which usually involves the use of equipment, facilities, services, personnel or information made available by one or more of the parties for use by the others. Such endeavors do not involve the transfer of funds or title to property between the parties, and are not considered a procurement or assistance transaction within the purview of P.L. 95-224. Services which may be involved do not constitute the employment of one of the party's employees by the other."

Given this definition, and an analysis of the legislative history of Section 305 of the Space Act and NASA's interpretation and application thereof over the years, this memorandum concludes that a joint endeavor is not subject to the legal constraints of Section 305, and that the allocation of property rights in inventions under any joint endeavor is a matter of agreement between the parties that must be specifically set forth in the joint endeavor.

12. Note 9, supra.

13. Note 7, supra.

14. This is based on the overall NASA policy to agree to protect only that data which can be protected under law, and to assure maximum protection for such data (Note 8, supra). As a practical matter this means providing the protection afforded under exemption (b)(4) of

the Freedom of Information Act (5 U.S.C. 552(b)(4)), which relates to (1) trade secrets, and (2) commercial or financial information obtained from a person and privileged or confidential. The court decisions (particularly the principle announced in Chrysler Corp. v. Brown, 441 U.S. 281, 1979) regarding this exemption make it clear that agencies have no discretion to release information that is a trade secret; that is, such information must be withheld unless there is another law (other than the FOIA itself) that specifically authorizes its release (which is not the case for information qualifying as a trade secret obtained by NASA under a launch agreement). However, there is a tendency in some courts to limit trade secrets to "technical" information for FOIA purposes. As a result, the decisions in FOIA cases are not all that clear regarding the release of commercial or financial information that is not technical in nature, but the courts do afford some discretion for an agency to withhold such information if release could cause substantial harm to the submitter's competitive position or impair the agency's ability to obtain the information in the future (i.e., the tests announced in National Parks v. Morton, 498 Fed 765 (1974)). This limited interpretation by the courts as to what may constitute a trade secret for FOIA purposes creates an anomaly as compared with the common law, where trade secret protection may be afforded to commercial or financial information that is not necessarily technical in nature.

In situations where an FOIA request is not involved, one recent, significant decision (Megapulse, Inc. v. Lewis, 672 F.2d 959 (1982)), drawing a close analogy to the principle announced in Chrysler, also prohibits the release by the Government of "trade secrets" obtained from a private party. It is not clear whether a trade secret in this instance will be as narrowly defined as the tendency of the courts in FOIA cases, but since the situations where Megapulse may be invoked are founded on a question of "fair-dealing" rather than on the interpretation of an exemption to a disclosure-oriented statute such as FOIA, a broader interpretation as to what constitutes a trade secret may be possible.

15. The agreed-to categories of "Releasable Information" in a joint endeavor for materials processing in space are general in nature and sufficiently adequate for NASA to inform the general public and appropriate governmental organizations of the overall objectives and the results achieved, and as may be needed for interface verification, payload integration and check-out. It does not, however, extend to internal design and processing details of the payload.

# FINANCIAL ISSUES FOR COMMERCIAL SPACE VENTURES – PAYING FOR THE DREAMS

by

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## ABSTRACT

Based on considerable work for private sector commercial communications satellite, launch vehicles, payload processing and other new space ventures as well as work for NASA on Space Station User Development, Mr. John Egan of Coopers & Lybrand's Business Planning Group will discuss the various financial issues involved in commercial space enterprises. Because Coopers & Lybrand is one of the largest public accounting and management consulting firms in the world a particular area of interest is the financial and investment issues associated with new business areas. As a result, much of the Firm's work in the space business area has concentrated on this area. Specific issues to be addressed in this presentation include: (1) the various stages of market development for different kinds of space ventures; (2) issues involved in attracting investment capital to space ventures; (3) characteristics of the players (entrepreneurs, large corporations, aerospace companies, venture capitalists, investment banks, commercial banks and the Government); (4) what is needed to make individual space ventures attractive to investors; and, (5) what can be seen as the prognosis for future financing over the long term development of a commercial presence in space. Particular emphasis will be placed on the materials processing area discussing the current state of business plan and financial developments, what is needed for enhanced probability of success of future materials development efforts in attracting financial backing, and, finally, a detailed discussion of the risks involved in this entire business area.

## DISCUSSION

Good morning Ladies and Gentlemen. I appreciate the opportunity to speak with you today concerning the financial issues of the commercial development of space – what I call "Paying for the Dream." We at Coopers & Lybrand have been working with both NASA and private sector corporations for some years now looking at the financial marketing and business planning aspects of commercial space ventures. We started out on the commercial side of the ledger doing work in direct broadcast satellite, expendable launch vehicles, communications satellites, and various other satellite related services. Subsequently, we have had contracts with NASA to develop commercial users for the space station, a comparison of marketing techniques between the Shuttle, Delta and Ariane and work for Bud Evan's Commercialization Task Force. What I hope to do today is to assist you in understanding how the commercial financial community views space related ventures.

There are five major issues facing us in looking at the commercialization of space and paying for that commercialization effort. The first is resources. Resources encompasses both financial resources that one has at present and the ability to attract additional money. Of course the financial strength of the organization is important, but the organization's commitment to

the space project is also important. A corporation with significant corporate resources that is not committed to such a program will not have as much weight as a corporation with less resources that is viewed in the financial community as having significant commitment to the particular project. A resource, in addition to the available resources within the corporation, is the corporation's ability to attract money. This ability is a function of both the project itself, the quality of the management, and the general financial perspective of the corporation as a whole.

The second major issue is risk. In looking at space ventures, there are two types of risks which must be considered. The first is what we will call normal business risk. This is the risk associated with any on-going business or venture. It involves such items as:

- Will there be a market for my product?
- Will the public accept the product at the price established?
- Can the corporation make a profit based on the price and other market conditions?

Such normal business risks are very well known to those entering into any type of venture and space-based or space related ventures are no different. However, space-based ventures introduce what I shall call extraordinary risks. These extraordinary risks are those risks associated with the difficulties rising from the inherently risky nature of operating in space at this time. The first and perhaps the most important is the transportation issue. It is much more difficult to go to space, process in space and return a product from space than it is to say for example, take your product from the warehouse in Dallas to the distribution center in St. Louis. In the latter case, there are multiple means available and though there may be accidents and problems, the general operation is considered to be routine. Such is not the case with space-based processing. Though the Shuttle is becoming more common in its use and flights are becoming more frequent, clearly there are inherent risks involved in such means of transportation. As has been demonstrated within the last week with the unfortunate failures of both the communications satellite launch due to PAM failure, the ability to provide secure transportation to the space environment is in question. Until these transportation and operating risks can be reduced and made more routine, an additional risk factor will always be associated with space-based production.

Additionally, in some areas of future space endeavor there are additional risks. Principally, these rest in the materials processing area. At this time it is not known whether certain processes can be effectively done in space in the materials processing area. While in theory these processes work and certainly some experiments have demonstrated that they will probably work in practice, we do not know what efforts must be taken to take these processes from the scientific phase through to the production phase. There is considerable risk inherent in the venture in developing products from experimentation to maturity.

The third issue is credit worthiness. Credit worthiness is basically how the corporation is viewed by investors. An unfortunate outcome of the high interest period some years ago was the development of the term called creative financing. Creative financing is one of the great euphemisms that has plagued the financial community. Some people feel that it means obtaining money with little effort, or perhaps more importantly, with no collateral or ability to repay. It is still true that there is no such thing as a free lunch. There is also nothing new under the sun when it comes to financing. Those who lend money and those who take equity positions



in corporations and give money to entrepreneurs and new ventures at start up are, ultimately, looking for a payback. This means that either the loan will be paid at some interest or that the business will be profitable to the degree that the investors will reap a considerable profit. As such, there is basically no free lunch.

The next issue is one of potential. This is a measure of how the new enterprise is viewed by the investing community. It is a combination of both potential for market development over time and the strength of the existing management of that corporation or project.

Finally, there are market conditions. This category breaks into two distinct sections. The first is the general economic conditions which will affect the development of any new enterprise. Whether or not the country is in a growth phase and the general economy will support the expansion of industry is very important to new ventures. The second is the market condition in the specific market for which the new product is being developed. In many space-based projects, the timing of entry into the market is very important. Since space-based projects require a certain period of time to come on line, there is a degree of uncertainty as to whether markets will exist or technological developments in related areas that are not space-based will develop in competition with space-based projects prior to their introduction.

Now that we have looked at the various issues that confront a corporation considering investment in space, let us turn now to the sources of funds that would be available for their use. The first and most important is internal or corporate resources. This represents the amount of corporate funding that the parent corporation is prepared to put into the space-based project. Other sources of funding are available but the amount of internal or corporate resources that is committed to such a project indicates better than any other measure the level of commitment and degree of support that has been generated within the corporation in support of the space related project. The level of corporate resources can be leveraged with other types of funding to expand the available capital base to do work in space. However, if sufficient internal or corporate resources are not available, it is very, very difficult to leverage any outside funding for a project that is not supported or is not viewed to be supported by the corporation with its own resources. In other words, it is very difficult to pay for such a venture with what would be considered other people's money.

If general resources are inadequate to make the space-based project viable by themselves, consideration may be given to selling ownership in the corporation in order to obtain funding to go ahead. This funding is generally called equity. It comes in several different varieties and we will discuss some of them here. First is a private stock sale. A private stock sale is a sale of ownership in the corporation on a private basis. That is, it is not publicly traded and not made available to all potential buyers but rather a select group of buyers chosen by those holding the ownership. Such private stock sales are not regulated in the same manner as public stock sales by the Securities and Exchange Commission (SEC). Private stock sales are a common way of raising equity for more risky projects in which stockholders expect a long term return but do not expect major dividends or other types of payment in the interim. For many emerging space-based businesses private stock sales have been the source of a fair amount of funding.

Public stock sales are the sale of common stock in a corporation in a public market place such as the New York Stock Exchange. Such sales are regulated closely by the SEC and historically have been a function of the public's perception of how well a corporation with a track and in history will mature, develop and grow over time. Given the long lead time of space-based projects it is unlikely that a new venture would be able to enter into a public stock sale

successfully. The public generally expects to see a return on its investment in a relatively short time, certainly within the first two or three years after purchase of the stock. With the long time frame involved in the space-based work such a payback period is unlikely. For companies involved in the more mature portions of the space industry, public stock sales are valuable means of obtaining additional equity. In addition, being involved in space-based ventures has considerable public relations value and it may be of benefit to a corporation in selling its equity to be sure that those in the public buying market are aware of their advanced technology in the space business.

There are several types of partnerships that could be looked at in terms of obtaining equity. Limited partnerships and limited R&D partnerships are the principal two. Partnerships differ from corporations in that the losses in a partnership flow directly to the personal incomes of the partners unlike a corporation which is a separate legal entity. The reasons people join limited partnerships or R&D limited partnerships are to accrue tax benefits and thereby shelter additional income derived from other sources. The purpose of this is to get into a venture when it is incurring losses or has high depreciation or other tax benefits such as investment tax credits or research and development tax credits and utilize them for their tax shelter benefits. The most important thing in such a partnership is to insure that the partner's tax benefits are maintained within the partnership structure.

Additionally, equity can be raised through joint ventures. A joint venture is when any two or more corporations agree to work together on a particular project. The exact structure of a joint venture may vary from an individual new corporation set by the two parent corporations to simply a working agreement or contract between them to complete the work.

The second major source of outside financing is debt. There are a number of ways of raising debt to assist in the financing of space-based ventures. Debt is almost always a part of such a venture given that the amounts of cash required are quite large. The three most common ways of raising debt are preferred stock in which a preferred stockholder receives some type of guaranteed or preferential return on the investment that is usually based on an interest rate the preferred stockholder is paid on an annual basis. This is very similar to any type of a loan agreement and therefore classified as debt rather than ownerships. Some preferred stock is convertible into common stock which has ownership value. Bonds are similar to preferred stock and sold on the market as debt instruments to the general public. As with the sale of public stock the ability to sell a bond is greatly dependent upon the cash flow and revenue of the company selling the bonds. As with most new ventures, it is very difficult for a space-based venture to sell bonds.

The final way to raise debt is through conventional bank loans. In order to obtain a loan a creditor must show adequate resources to pay back the loan with the interest applied by the banker. For ventures which have some degree of risk, as most space ventures do, the interest rates charged by banks for a loan may be higher than that given for other types of loans. The conventional debt portion of any space-based venture may become substantial given the amount of funds required for most space-based projects.

The amount of debt which a project can raise is very much a function of the amount of capital that has been invested in the project and the class or quality of the corporation or individuals who stand behind the venture. To some degree the venture is transparent to its financial backers. The bank will wish to be assured, through some kind of contractual arrangements in establishing the debt requirements and making the loan available, that they will be receiving their

payments as required. This may mean that the investors, either corporations or individuals, will have to back or guarantee the loan to be used for a space-based project.

Finally, there is venture capital. Venture capital is a type of equity arrangement in which a venture capital firm takes a position in a corporation by making a large equity contribution for which they receive a substantial amount of stock and become major advisers to the corporation. Venture capital deals are very difficult to establish on space-based projects. There are two basic reasons for this; first is the long payback period and second is the large amount of capital required. Most venture capital deals require payback to the venture capital firm within three years. Most space-based projects have much longer time frames than three years. Secondly, and perhaps most importantly, a \$1 or \$2 million venture capital deal is a very large venture capital placement. Most space ventures require significantly more capital than this to get started. As a result, they are not of great interest to venture capitalists.

Now that we have reviewed the various potential funding methods, I would like to turn now to what is called the product life cycle curve. This curve, which is presented with the slides from this presentation at the end of this paper, is a way of looking at the business cycle for any product. It is not unique to space-based ventures but applies to any and all types of projects. Basically, there are five phases – the pre-commercial phase in which money is expended and no income is received because the product development is underway. A point at which the product is introduced is called the introduction phase, at which time sales begin to pick up and some profit or some return is received. During the introduction phase there are heavy costs for advertising and other introductory expenses. We then move to the growth phase in which the product's growth continues to rise and rises rapidly; it is during this phase that the product hopefully begins to return a profit or certainly return significant revenue. During the maturity phase the product reaches its maturity and becomes a well established product. Products maximize revenue during this period. The final period is the period of decline in which the sales volume and profits drop off. It is usually during the maturity phase and in order to avert the decline phase that new and improved versions of the product are introduced in the hopes of continuing the product along a generally upwardly sloping curve.

We introduced the product life cycle as the way of looking at the various places in which the space businesses are at this point in time. Communications satellites, for example, are clearly in the growth phase of the product life cycle. They are an established business with customers. They are making a profit and they are a growing business. As a result, they have the same type of characteristics as any product in this particular phase. Earth observation, on the other hand, is in the introductory stage and is trying to move into a growth stage. Finally, such products as materials processing or the building of space structures are in the pre-commercial stage in which money is being spent to develop them as products but no income can be seen at this time and income may be some time in coming. For MPS, it may be some time before products are even introduced. However, with the McDonnell Douglas electrophoresis program, introduction for their pharmaceutical products may be in the near future.

We make this analogy to point out that when each of the businesses is a different phase then different types of financing are appropriate. For a maturing business, that is a business on the growth cycle, such as communications satellites, the funding mechanisms would include internal resources, conventional debt and equity participation. For a product near introduction or newly introduced, internal resources would be necessary along with venture capital as a possibility, and conventional or other types of equity participation. For a new technology at the

start of a development, internal resources and equity participation are the principal available means of funding such projects. R&D partnership money may also be available for those types of industries.

Turning now to the investment obstacles that face any investor looking at space related venture, the first, and perhaps the most important, is the time obstacle. The payback time for most new space-based ventures, particularly in materials processing or other long term investments is significant. Some funding sources are, therefore, not available to such start-ups. For investments that are related to communications satellites, the launching of satellites or satellite related technologies the payback time may be significantly less and this may not be as great a roadblock as it is for those newer technologies. The second obstacle is very large capital equipment costs involved in virtually all space related investments. Such large capital equipment costs close out smaller businesses and smaller investors to some degree. A \$1 or \$2 million investment for any type of venture firm or equity investor or, for that matter, lender, is a significant amount of money. Many, many space ventures require significantly more money than \$1 or \$2 million. A part of the problem is a perception one for those that have been involved in space ventures for some period of time. We tend to speak in terms of multi-millions of dollars as if that were nothing. This is not in fact the case, and those who are going out and need to raise money must be aware that it is extremely difficult to get people to invest significant amounts in high risk ventures. It requires more than a strong personal commitment to the future of space.

The funding options available, as has been discussed throughout this paper, are restricted because of the two issues we just discussed. There is a reduced availability of venture or other types of speculation capital because of the reasons we have stated. Though large sums and long paybacks make such ventures difficult to finance, the upside potential of space ventures can go a long way, as we have discussed earlier, in off-setting these downside risks. However, the person seeking funding must be aware that this upside potential will not be able to off-set some or all of the hesitancy of either the equity investors or lenders. As a result, strong advocates and a strong business plan are essential in the development of any funding scheme.

Finally, there are three smaller obstacles. First is a management obstacle in that for many corporations short term paybacks are more important than the longer term paybacks. Since most space ventures are long term payback the manager whose future is career success based on some elevation using some type of short term measure, such as return on investment or return on equity, may be less interested in a space venture with a large equity and long payback requirements. The investor is also faced with a perception of technical risk – the risk involved with the transportation and manufacturing processes as opposed to the normal business risks of market – the desirability for the product or other market forces. To the degree that Shuttle transportation, space station operations and other types of space related manufacturing techniques become less novel and more routine that will benefit the space investor. Finally the nature of the business is quite entrepreneurial and not without risk. As such, the nature of the business requires that the investor be in the leading edge of their industries and be early adaptors or persons interested in accepting the risk for future reward. The future rewards of space-based technology are not guaranteed. As a result, those willing to take the chances should reap great rewards when rewards are forthcoming, but should be aware that the initial losses may be significant and the road is not an easy one.

## C&L WORK IN SPACE-RELATED INDUSTRY

### NASA

- COMMERCIAL USER DEVELOPMENT FOR SPACE STATION STUDY BEGUN APRIL 1983
- COMPARISON BETWEEN STS, DELTA AND ARIANE STUDY COMPLETED JULY 1982
- SPACE COMMERCIALIZATION STUDY (PENDING)

### PRIVATE SECTOR

- COMMERCIAL EXPENDABLE LAUNCH VEHICLES – MARKETING AND FINANCING ISSUES
- DIRECT BROADCAST SATELLITES – BUSINESS PLANS AND FINANCIAL FEASIBILITY STUDIES
- COMMUNICATIONS SATELLITE MANUFACTURERS – MARKETING AND FINANCIAL ISSUES
- SATELLITE SERVICE PROVIDERS – FINANCIAL AND BUSINESS PLANNING

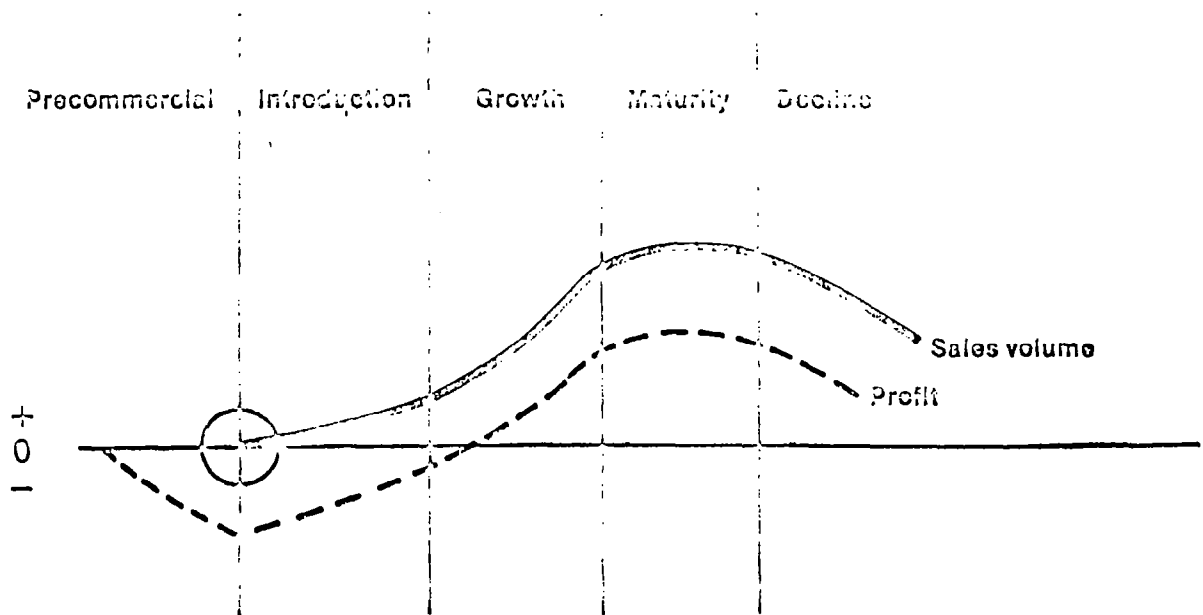
### MAJOR ISSUES

- RESOURCES
- RISK
- CREDIT WORTHINESS
- POTENTIAL
- MARKET CONDITIONS

## SOURCES OF FUNDING

- INTERNAL (CORPORATE RESOURCES)
- EQUITY
  - PRIVATE STOCK SALE
  - PUBLIC STOCK SALE
  - PARTNERSHIP
  - JOINT VENTURES
- DEBT
  - PREFERRED STOCK
  - BONDS
  - CONVENTIONAL BANK LOANS
- VENTURE CAPITAL
- R&D PARTNERSHIPS

## PRODUCT LIFE CYCLE



## WHERE IS THE BUSINESS?

- MATURING INDUSTRY
  - COMMUNICATIONS SATELLITES
  - EXPENDABLE LAUNCH VEHICLES
  - SATELLITE PROCESSING
- DEVELOPING INDUSTRY
  - EARTH OBSERVATION
- NEW TECHNOLOGY
  - MATERIALS PROCESSING

## APPROACHES TO CAPITAL MARKETS

DIFFER DEPENDING ON STAGE OF MATURITY OF THE PRODUCT:

- MATURING BUSINESS
  - INTERNAL RESOURCES
  - CONVENTIONAL DEBT
  - EQUITY PARTICIPATION
- PRODUCT NEAR INTRODUCTION OR NEWLY INTRODUCED
  - INTERNAL RESOURCES
  - VENTURE CAPITAL
  - CONVENTIONAL DEBT
  - EQUITY PARTICIPATION
- NEW TECHNOLOGY AT START OF DEVELOPMENT
  - INTERNAL RESOURCES
  - EQUITY PARTICIPATION
  - R&D PARTNERSHIP

## INVESTMENT OBSTACLES

- TIME – LONG PAYBACK
- LARGE CAPITAL EQUIPMENT COST CLOSES OUT SMALLER BUSINESSES.
- REDUCED FUNDING OPTIONS – REDUCED VENTURE/SPECULATION CAPITAL INVOLVEMENT.
- LONG TERM VERSUS SHORT TERM.
- INVESTOR PERCEPTION OF TECHNICAL RISK – RISK INVOLVED IN TRANSPORTATION AND MANUFACTURING AS OPPOSED TO BUSINESS RISK.
- NATURE OF THE BUSINESS



# SPACE INDUSTRIALIZATION – A NATIONAL PERSPECTIVE

by

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## ABSTRACT

Space Industrialization (or commercialization) has the potential to be a major player in our nation's space program. If this potential is to be realized, however, industrialization efforts must be considered within the context of the other major portions of the space program: shuttle, space station, civil remote sensing, etc. Further, development efforts must be based upon a sound scientific and technical understanding of the products and processes, and there must be a trained cadre of dedicated individuals willing to devote time and effort to this effort.

There remain considerable risks and uncertainties. Given all this, the best path to follow would seem to be a long term, balanced commitment, emphasizing government, industry and academia partnerships.

## DISCUSSION

When President Reagan announced the new national space policy on July 4, 1982, he could have made space industrialization the major new initiative of our space program; perhaps even setting the goal of the first space industrial part by the end of the century. But he didn't. The space industrialization words in the policy were much, much less dramatic. Let me quote them directly.

“The United States encourages domestic commercial exploitation of space capabilities, technology, and systems for national economic benefit. These activities must be consistent with national security concerns, treaties and international agreements.” And,

“The United States Government will provide a climate conducive to expanded private sector investment and involvement in space activities, with due regard to public safety and national security. These space activities will be authorized and supervised or regulated by the government to the extent required by treaty and national security.”

Neither of these statements would ever be confused for a clarion call for action, yet beneath them lie a challenge that if accepted and fulfilled could someday – maybe – be as significant as President Kennedy's challenge to go to the moon some twenty years earlier.

What I shall do today is describe a perspective on where space industrialization fits into our national policy and programs and what I believe to be the nature of the space industrialization challenge. To do this I will consider several different national views. The first of these is programmatic – where does space industrialization fit in with the other national space programs?

The second is more philosophical in nature — what does space industrialization mean with respect to the historic, national aims of space? Finally, I will briefly comment on substance; what is it, in fact, that is being industrialized?

Our space program can be divided into two parts; military and civilian, and the civilian part in turn can be categorized as public and private. (The latter is almost entirely made up of the communication satellite business.) The separate U.S.-government civil and military programs are about equal in size, around seven billion dollars a years each — and each of these are perhaps twice as large as the Comsat business. (As an enterprise, the total U.S. civil space business is about the same size as the U.S. diet and exercise business.)

Within the U.S. government of course, NASA is the five hundred pound gorilla in civil space, but other agencies and departments also have a strong role in developing space policy and the programs that flow from that policy. Thus, any new initiatives in space industrialization would come under scrutiny of the Department of State, who would be concerned about how such initiatives affect international treaties and foreign relations; the Department of Defense who would be concerned about possible transfers of technology to potential adversaries and so on and so on down through all of the government players.

Within NASA, space industrialization must be viewed against a background of a wide variety of continued and expanding programs. These include the space shuttle and space lab, other launch vehicles, the unmanned space science program, which includes planetary exploration, astronomy and space physics, and of course the space station. This is a full plate and one that is rich with promise. Further, while space advocates are quick to point out that civilian space represents but a small fraction of a \$900 billion federal budget, it represents a much larger fraction of the discretionary deficit. In short, there is a lot of good, stiff competition for the space program dollar.

Next, we come to the issue of how and why industries are created and why and how we have a space program. There is a difference. Listen to business men talk and you hear expressions such as return-on investment, discounted-cash-flow, present value, future value, interest and yes — profit. These terms are not often in the vocabulary of the NASA planner. NASA was put together in large part for the exploration — not exploitation — of space and that exploration is in no way ended. Far from it. Further, with a few notable exceptions, NASA does not have the expertise to do research on commercial products, because commercial products don't really play much of a part in space exploration. It's not that people at NASA are in any way antagonistic toward commercial enterprise, it's just that commercial enterprise really is very different from what NASA does and people know and feel comfortable with what they do best.

Finally, we must look not just at the background, but the substance of the space industrialization. Are there in fact products and processes which can be developed in space which can make a real difference to the U.S. economy? Is there enough so that a market can be created that is fair and competitive? The evidence to-date is, frankly, mixed.

Communications has been successful as a commercial enterprise, land remote sensing has not, and the jury is still out on materials processing. Indeed, a better legal analogy for MPS is that court is not even in session! With a few noteworthy exceptions, the private sector has not yet developed the concepts, or will, necessary to transfer enterprise into space. This was expressed best by the distinguished Senator from this state, Senator Heflin, at the recent hearing on the space station where he differentiated between interest, involvement and commitment.

Quoting Senator Heflin,

**“If you are interested, you are willing to spend someone else’s money, if you are involved, you are willing to spend your brother-in-law’s money; and if you are committed, you are willing to spend your own money.”**

Up to now, I think we can conclude, space industrialization has evoked a lot of interest, some degree of involvement and only a little commitment.

Given these three elements; strong programmatic competition for the civilian space dollar in a difficult national budget situation, a civilian space culture that is oriented towards public exploration rather than private economics and a lack of broad based commercial success or private sector financial commitment, it should come as no great surprise that the 1982 space policy toward space industrialization was not more aggressive. Indeed, one could conclude that it took some degree of faith to go as far as it did. Given that statement, however, let’s now take a look and see just how that policy is being implemented.

In the interagency arena, you’re aware, I’m sure, of the Presidential directive last May permitting the use of government launch pads and related facilities available to private firms at nominal cost, and the subsequent directive giving the Department of Transportation lead responsibility in this arena. And you will hear later in this symposium about what’s happening in the attempt to transfer land remote sensing to the private sector.

But the primary government player, of course, is NASA. And what NASA did was put together a task force. To lead that task force, they chose an individual from outside the space community but with considerable experience both within government and the private sector and with a track record of accomplishment. That’s Bud Evans. The members of the Task Force were chosen from both headquarters and the various NASA centers and they were supported by a strong team of contractors and consultants. I’m not going to describe in any detail the output of the task force, but it is important to consider how the task force tackled the problems described above. First the programmatic.

Space industrialization or commercialization has an obvious problem with identity – it means different things to different people. This leads to difficulties in defining specific programs. Budgets, in-turn are allocated to specific programs, so that definitions are not just an academic exercise. The relationships between commercialization efforts and other NASA programs, particularly the Shuttle and Space Station programs, are very important. Maintaining a distinct, high level presence at headquarters will go a long way toward helping to clarify and identify issues with respect to programs, and the task force recommended maintaining such a presence.

Such a headquarters element, with access to the highest levels of NASA decision making can also play a pivotal role in the second major issue, the relationship between industrialization and the exploration philosophy that has driven so much of our space program. Removing legal, regulatory and operational barriers to accessing space will both shorten the time and cost of commercial operations and will also help develop professional relationships between people as they seek to work together. The task force developed specific recommendations in this regard.

Finally, and perhaps most important, we come to the substance issue. Task forces, even the best ones, don’t actually produce anything but paper and viewgraphs and sometimes ideas. One idea that has struck me as particularly fertile is the suggestion to begin several space industrialization “centers of excellence”; institutions based in academia, but with industrial and

government support. The mission of these organizations will be not just to generate research projects, but to produce a generation of young scientists and engineers who think of space as a place to exercise creativity. Such centers have traditionally been a rich source of ideas, experiments and entrepreneurs.

I don't know at this time which, if any of the task force recommendations will be accepted, but I do think they represent a thoughtful approach to the problem, one that is clearly responsive to the national policy.

Well, what does this all mean? Given these perspectives, what is the best way to develop a private space industry that is in the national interest? Did we make a mistake in not pushing space industrialization harder as a national goal? I don't think so. I think that there is a real danger in overselling the economic returns from space commercialization, both in terms of absolute magnitude and (especially) in terms of how long it will take to get that return. Our experience with land remote sensing is a clear and persistent example of this. Further, overselling the economic return is not necessary. It is not exploitation versus exploration that is at issue here. Indeed let me suggest that there is a striking similarity between the entrepreneur who is willing to risk what he holds dear – his capital, and the explorer who is willing to risk what he holds dear – his life – on something that hasn't been done before. To succeed in either field requires that you do the proper homework, calculate your chances as accurately as possible and be brave. When looked upon in that perspective, both the entrepreneur and the explorer can share in the national adventure which we call the space program.

# THE COMPUTER-COMMUNICATION LINK FOR THE INNOVATIVE USE OF SPACE STATION

by

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## ABSTRACT

The potential capability of the Computer-Communications System Link of Space Station will be related to innovative utilization for industrial applications. Conceptual Computer Network Architectures will be presented and their respective accommodation of innovative industrial projects will be discussed. To achieve maximum system availability for industrialization is a possible design goal, which would place the industrial community in an interactive mode with facilities in space. A worthy design goal would be to minimize the computer-communication management function and thereby optimize the system availability for industrial users. Quasi-autonomous modes and subnetworks will be key design issues, since they would be the system elements directly effecting the system performance for industrial use.

# THE REAL WORLD – THE USER

by

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## ABSTRACT

Satellite communication is by far the most advanced of all commercial applications of space technology. This presentation will look at the past, present and some future possibilities for the field of public communications. It will also examine some serious concerns that are becoming apparent to the user of this technology.

## DISCUSSION

“Sputnik” – “Vanguard” – “Explorer” – “Score” – “Echo” – “Telstar” – “Relay” – “Syncom” – They are all names that have little meaning to anyone under the age of 25, yet, every one of them has played a critical role in the ever advancing technology of space communications and its development as a commercial venture.

To those of us who were around then, – who can forget the surprise and shock of hearing that faint electronic beep-beep-beep from a small globe circling the Earth – put there by the Soviet Union in October of 1957 – “Sputnik” – the first man-made satellite.

Or, the despair on that day several weeks later when some of us stood on the beach and watched as “Vanguard” – this country’s first orbital effort for the Geophysical Year – rose – fell back and exploded on a launch pad at Cape Canaveral.

And, isn’t it prophetic that we should be meeting here in Huntsville where Wernher von Braun and his team hastily put together the first U.S. satellite – “Explorer 1” for launch in January of 1958.

But, it was project “Score” – launched on top of an Atlas rocket, number 10B to be exact, carrying President Eisenhower’s Christmas message to the world from low-earth orbit in December of 1958 which truly started the age of satellite communications.

Commercial enterprise quickly recognized the potential of space communications and the AT&T “Telstar” low-earth orbit satellite was the first step in what has developed into a world-wide communications network which is operated by INTELSAT as a consortium of participating nations. To those of us in my business, Public Communications, it was an incredible breakthrough. I remember sitting in a television control room and bringing to the viewing public LIVE pictures from London for the first time ever. A new dimension to a rapidly advancing technological society. But, those brief minutes of Telstar “opportunity windows” were limited and

complex because the satellites were in low-Earth orbit and had to be tracked across the sky by large motorized dishes during the “passes” which brought them above the horizon in view of Andover, Maine and Goonhilly, England.

Sir Arthur Clarke’s prediction of geosynchronous satellites got its first test with “Syncom II”. Although never designed with television in mind, it was in fact used for that purpose in October of 1964 when the entire opening ceremonies of the Summer Olympics in Tokyo were transmitted LIVE to the United States. It proved the point for us.

The dam had burst, and the Earth was getting smaller. With the development of the INTELSAT global system, and domestic regional capacity, it is now possible to provide almost instantaneous and continuous communications from just about any place on the Earth. We are able to see and hear with commonplace regularity the sights and sounds of events like the Winter Olympics taking place in Sarajevo, Yugoslavia this week, or watch a war with its death and destruction from Lebanon or the Falkland Islands.

Maybe, someday, such tragedies won’t occur because they are no longer abstract events when people see them happening in real time.

All of us in this room are involved in industries that are undergoing tremendous change. And for me, modern technology has – and continues to – revolutionize the information and communications business.

My purpose in being here is as a user – not to entertain, but to perhaps give you some thoughts for the future.

How often have we heard the phrase, “There’s nothing new under the Sun?” We heard it used earlier by John Egan in a very affirmative manner.

Well, unless the laws of physics and chemistry are wrong, that is true. What is new, however, are the uses to which we put the knowledge gained from those laws and our experience. To do that successfully takes imagination, human ingenuity, a little luck, and a lot of guts.

Public communications has been far from immune to new ideas, and television has been one of the most volatile segments of that field. (Perhaps, though, it might be better to replace the word “television” with “CRT Usage”.) Change is running rampant.

To quote from an article I read in the Atlanta Constitution not too long ago: “It is as if the entire industry has come off the highway it has always known, and onto a traffic circle with several exits. A few companies are circling, trying to decide which road to take to get farther ahead. Others are driving down new roads – but they’re watching in the rear view mirror to see where the rest are heading – and wondering if they’ve done the right thing.”

Visualize, if you will, that traffic circle with exit signs labelled “Cable,” “Videotext,” “Wired Society,” “Addressable,” “Interactive,” “High Definition,” and “Direct Broadcast.”

Let’s examine a couple of those roads and see where they lead. In actuality, some of them will merge again over the horizon.

One of those roads – Cable TV – has had explosive growth. How did it all start? Interestingly, it started with a small appliance dealer in the hills of Oregon in 1948. He had television sets for sale in his store, but because the community was in a valley, no one could receive the signals coming from the nearby metropolitan center where the TV stations were located. Using his ingenuity, he installed an antenna on top of a nearby hill where he could get the signals, and ran a wire down into town so those television sets could receive the programs. CATV, community antenna systems to bring the signals into fringe areas. The first cable systems.

Federal regulations limited the amount of service they could provide, and restricted their growth in major population centers. In 1965, cable served only about one million households in the entire country.

Over the next ten years of regulatory “jockeying” cable grew slowly. Late 1975 and early 1976 brought the turning point not only with “rules” changes, but the dawn of satellite distribution. The use of private enterprise communications satellites for central distribution of programming became a reality. With just one channel of a domestic satellite in geosynchronous orbit, a signal from one ground station can be sent to any location in any area all the way from the Carribean Islands and Maine in the east, to Alaska and Hawaii in the west. And, as many points in between that have satellite dishes. Point to multi-point distribution. Today cable is reaching over 31 million homes.

Those satellite dishes started popping up like mushrooms not only at cable systems, but in back yards all over the country as the cost diminished. Some of you may recall the 1979 Nieman Marcus Christmas catalogue which showed a TV satellite receiving dish for \$35,000. Today, a similar installation can be done for about one-fourth that cost. And, there are some home units selling for under \$1,000.

Satellite delivery has created a new, or substantially changed, market place and opened avenues for innovative thinking. My boss, Ted Turner, is certainly one of the leading examples of someone with that capacity for innovation. We now have four services which are satellite delivered. Superstation WTBS, Cable News Network, CNN Headline News which not only services cable homes but a network of television stations across the country, and CNN Radio. And, it isn't only domestic. We provide several hours a day to an Australian Network via INTELSAT, and shortly will start direct service to Japan. The U.S. Armed Forces Network carries a substantial amount of our programming worldwide.

The globe is getting smaller.

But what about some of those other exits off of the hypothetical traffic circle?

High Definition is coming, and the only practical way to deliver it is by satellite.

So is Digital television. It is interesting that the only real impediments to a functional digital television system are the existing television station transmitters and the millions of existing TV sets which are analogue. Within most television production centers today, signals are converted continuously from analogue to digital and then back to analogue for transmission to the home receivers.



I see the day, not too far away, when someone will market a component digital television receiver which becomes part of an ever more sophisticated home information center.

We are all very much aware of the exponential growth of home information tools. Just look at the sales figures for home computers, video cassette machines, video games, and digital stereo systems. And, I certainly don't see any slowing of that growth.

The growth and changes haven't all been restricted to television either.

The printed media have become painfully aware of the necessity for change. A couple of years ago a major study was undertaken to examine the impact of electronic information systems on publishing. Particular attention was given to the key events that could influence the evolution of, and the interaction between home electronic systems and the print media.

The computer age already has changed the inside of the newsroom, and inevitably will change the way newspaper produce reaches the subscriber. The traditional system of delivery — from plant to truck to delivery person to front door — cannot survive. It is too costly and too time consuming. We all have been made acutely aware of the problems of some newspapers over the past couple of years, and we mourn the passing of such outstanding publications as the Washington Star, The Philadelphia Bulletin, and others.

Now, I am not one of those sounding the death knell of newspapers, however. I think that generally their future is secure, as long as they recognize the need to adapt to changing conditions, and act accordingly. Electronics should not be viewed as a threat, but as an ally. It will allow the transmission of textual information directly into the home bypassing today's outmoded and economically unfeasible system. Some are already trying it. Newspapers such as USA TODAY, The Wall Street Journal, and The New York Times are being centrally prepared and satellite fed to printing plants around the country. Can transmission either by cable or direct to the home be far behind?

Generally, home electronic services can supplement and compliment printed features if publishers take timely advantage of the electronic trends underway and build a capability to provide electronic information services.

A key element in the growth of those services is the extent of penetration of households by electronic equipment. I've already pointed out the growth rates of cable TV, home computers, video cassette machines, and satellite receivers. So those signs are all there.

I expect by the end of this decade we will be seeing a massive transmission of data into the home and office. A person will be able to punch a few buttons to select a multiplicity of information sources on their CRT or "information frame" hanging on the wall — which uses liquid crystal display technology.

The information explosion which is engulfing all of us can't be all one way though. There has to be a form of inquiry and selectivity beyond the knob on the television set or the converter box which provides selectivity amongst all those channels. Everybody doesn't have a need for all that information all of the time, and we can't store it all in that desk top computer terminal we're beginning to live with.

That brings us around to a couple of more exits on the traffic circle – “Addressability” and “Interactivity.”

The information supplier doesn't necessarily want his product to be received by all those millions of possible recipients out there. The entrepreneurs who are busy developing electronic mail delivery don't want you or me reading somebody's steamy love letter to his girl friend or a proprietary business proposal between two companies. So, there is a real need for a secure method of establishing discrete one-way communications and multi-faceted high speed interactive two-way services.

Perhaps the tremendous growth of electronic banking service is one of the best examples of the direction we are headed.

Security of product is a major issue. In some quarters of our business, piracy is rampant. The pay television services are losing millions of dollars per year through theft of service. That's why they are pouring large resources into the development of alternative approaches to the way they are currently operating.

Just yesterday I heard of a group of high school kids going around a newly cabled neighborhood offering, for \$10, to “fix” the subscriber's cable tap so they could receive the premium services.

What's the answer?

Scrambling is one. But, in this day and age it doesn't take very long for a good electronics mind, or a high school whiz, to figure out how to unscramble a signal.

Individual addressability is better. That's relatively easy in a “closed loop” or wired system, but not so easy for a mass single point to multi-point network of millions of homes. And, its still only one way.

I'm sure some of you out there are saying, “This is all very interesting, but what has it got to do with a Symposium on Future Space Industrialization?”

There can be little doubt in any of our minds that communications industries have been the greatest beneficiaries of space activities. It is the most highly developed and commercialized of anything to come out of the space program. So what's left?

Lots!

Back in 1973 I wrote an article for the Overseas Press Club magazine titled, “2001 – It's Old Hat” which described some of the tools which I believed would be available to the television journalist of the future.

I said he would wear a device – perhaps the Dick Tracy wrist watch – which would provide him with two-way satellite voice communication with his home office from anywhere in the world. He would carry a camera and recording device probably no bigger than today's home movie cameras. He would have in his electronic briefcase a small “pop open” inverted umbrella antenna with pointing instructions which would allow him to increase his two-way

capacity to include video transmission. He would have a micro-miniaturized computer/printer terminal that would allow him to query and receive printed research material, and transmit his completed report back to his home base.

Doesn't sound that far fetched does it?

Some people thought I had lost it back then in '73, but let's look at where we've come since then. At that time, the camera and recorder combined weighed over 100 pounds – today its about 15 to 20 and getting smaller. Back then a briefcase computer terminal was unheard of – today they're commonplace. Back then you had to find the nearest telephone booth to talk to the office – today ground-based mobile systems are everywhere and growing at break neck speed with the development of cellular radio. The portable satellite uplink may not be briefcase and umbrella size, but they are getting smaller and more mobile every day. If we can make one that can drive around on the moon's surface and send signals to Earth, we can sure do it a lot closer to home.

What's a Space Station going to do for me – the user in the next few years?

To start with, it's going to manufacture microprocessing and storage chips which are so dense in their capacity that my whole reporter's system might be no bigger than a pack of cigarettes. The lens will be the biggest thing on the camera/recorder. And, speaking of that, lenses will be developed in space that will be so pure that they will be close to perfect transparency in their light transmission characteristics.

Solar power generation cells will be manufactured that are so pure and efficient as to make today's look like a Model T compared to the Space Shuttle. And, those same cells will be assembled into "power wings" that will drive propulsion systems to get me where I want to go – the geosynchronous highway.

Up there will be real switchboards in the sky which have been assembled in low-Earth orbit. The manned space tugs will carry the parts and pieces from low-Earth orbit so that we won't have the horrendous hundred million dollar losses like the ones we saw last week when two communications satellites didn't make it. In other words, a geo-platform.

The future generations of communications stations will have arrays of steerable antennae which will allow spot beams narrow enough to service individual cities, or broad enough to cover the whole country. They will be able to talk to other satellites in the arc so that it won't be necessary to come back down to Earth in order to get more than one third of the way around the globe.

There will be enough power generated on board those satellites that signal strength back down to Earth from high technology advanced high power amplifiers will be sufficient to allow individual home receivers that use "dishes" no bigger than a coffee cup saucer. Full range, direct broadcast will be a reality. Receiving antennae on the satellites will be big enough that they can receive "mini-power" signals sent from those very same coffee cup saucers making every one of them in individual homes or offices addressable, interactive, and discrete to a vast array of information sources.

Those space based switchboards will be able to maximize the interface between a myriad of frequencies. Today we're scratching the surface of KU and KA band utilization. There's

still a lot of spectrum beyond that to be challenged. And, with the demand for positions in the orbital arc all around the world, we're rapidly running out of room.

To some there may appear to be a glut of capacity today, but I guarantee you that it won't last very long, and we must develop the capacity to accommodate future needs. And there has to be redundancy and flexibility to provide protection.

One of my greatest concerns today is the security of our system. In recent months there have been several occasions when users, such as ourselves, have been "wiped out" by interfering transmissions. Today it is possible for almost anyone with a good electronic knowledge to buy off the shelf parts and put together a home made transmitter that could seriously impair the Public Communications industry. We must have alternatives that guard against such occurrences.

I've postulated on a lot of things in just one tiny segment of the potential industrialization of space. Is there a market there? That's for you to decide. I certainly believe there is. Space communications is the most cost efficient method of moving information, and our society increasingly demands and uses more information faster and in greater quantities than we can conceive.

I don't see any diminishment of that demand. Earlier, I used the phrase "Nothing new under the sun." Well, I don't believe a word of it!

# OPPORTUNITIES FOR SPACE BIOPROCESSING

by

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## ABSTRACT

Space bioprocessing has been thrust into an unexpected limelight as a result of the pioneering McDonnell Douglas/Johnson & Johnson experiments in continuous flow electrophoresis. Thus, there is an urgent need to reassess the opportunities and pitfalls in this area of space commercialization.

NASA's program of space bioprocessing may become the unwitting beneficiary of equally revolutionary recent ground-based developments in genetic engineering and other allied areas of applied biology. As a result of these advances, a number of important new biologicals have become available in unlimited quantities, subject only to the proviso that adequate purification methods can be devised. It is not an exaggeration to state that the need for ultimate purity is a major bottleneck in this emerging industry. NASA's space bioprocessing program may become a key factor, as mandated by ever increasing needs for sophistication in purification technologies.

Our process of recycling isoelectric focusing is characterized by very high purity of final products. A key question is whether space provides sufficient advantages over our ground-based process. A first pilot experiment is planned for STS 11, scheduled for January 29th. While primarily an experiment in basic science, it was designed to provide crucial information on the likely performance of focusing in a microgravity environment.

## INTRODUCTION

It is a pleasure to participate in this Symposium on Space Industrialization. The opportunity to do so is particularly appreciated in view of the successful McDonnell Douglas/Johnson & Johnson space electrophoresis experiments. They have suddenly thrust us into a radically new era of industrialization of space. With it, they have imposed on us, the other space-concerned biotechnologists, the need to reassess the opportunities and pitfalls of operations in space.

In this context, I will address the following points: (1) The need for improved purification technologies; (2) the role of electrophoresis; and (3) isoelectric focusing.

## PURIFICATION TECHNOLOGY

We are in the midst of a revolution in applied biology due to advances in genetic engineering and the allied fields of monoclonal antibodies, synthesis or isolation of individual

genes and solid phase synthesis of peptide hormones. The social and economic impacts of this new biotechnology have been amply covered in the scientific as well as lay press, including an authoritative review by the Office of Technology Assessment of the U.S. Congress (1).

These technologies have rendered possible the production of virtually unlimited quantities of important new biologics, which were previously available only in minute quantities. Interferon, human growth hormone, a foot and mouth disease vaccine, are but a few of such pharmaceuticals which can be cited as examples.

It should be emphasized that these biologics are often first obtained in the form of crude extracts, heavily contaminated by extraneous matter. For example, in recombinant DNA, a gene, coding for the desired pharmaceutical, is implanted into bacteria or yeast, thereby "engineering" the microorganism to produce a protein which it normally does not synthesize. The new protein has to be separated from the myriad of other proteins native to the microorganism. Similarly, monoclonal antibodies are produced by hybrid cells, obtained through the fusion of an antibody-producing lymphocyte and a cancerous cell. It is the cancerous moiety which confers to the hybrid its ability to rapidly reproduce. Again, the monoclonal antibodies need to be separated from the other proteins of the hybrid cell. The magnitude of the problem can best be visualized if one realizes that the host cells, the modified microorganism or the hybrid, may contain well over 5,000 different proteins, only one of which is the desired active principle.

The utmost in purity is essential for any of these products to be administered to a patient. Present purification technology is as much an art as a science, and is often a major bottleneck in production. It mostly involves a series of purification steps, artfully sequenced until the required purity is obtained. Chromatography is the main workhorse, and the whole process is costly and inefficient – at times only a minute fraction of total material synthesized is obtained in purified form.

We are only at the beginning of this revolution in biology. Modified plants and animals are on the horizon. It is indisputable that these advances will require ever increasing sophistication in the art of separation and purification. Thus, NASA's program is the unwitting beneficiary of these new developments and may become of crucial importance for future biotechnology.

Many of the biologics are in a price range which could justify space processing. Their unit value may exceed millions or tens of millions of dollars per kilogram. On the other hand, total demand may be only a few kilograms annually. Any new separation process has to have high resolution and high yield, that is, isolate the desired product in high purity and with minimal losses.

## ELECTROPHORESIS

Electrophoresis is a most elegant technique for the separation of complex mixtures of biological origin. Because of its unique usefulness, a great variety of instruments have been developed and these are used in literally thousands of laboratories the world over. Most of this usage, however, is confined to analytical applications only, and is of little relevance to the task at hand, namely the purification of pharmaceuticals on an industrial scale.

At present, a paradoxical situation prevails. Analytical electrophoresis, in particular the so-called two-dimensional electrophoresis, offers the highest resolution of any separative technique and is routinely utilized for quality control in the production of biologicals. Nevertheless, no form of electrophoresis is utilized for the actual production of these compounds. In the past the requisite instruments may not have been available, but this is no longer true. It should be emphasized, however, that no single technique, chromatographic or electrophoretic, can be a panacea for all separation problems. Instead, they all should be considered as components of an increasingly more complex armamentarium of purification methods, to be integrated in an overall production scheme.

Three electrophoretic instruments are presently available for large scale processing:

1. The McDonnell Douglas continuous flow electrophoresis apparatus. This type of instrument was pioneered by Prof. Hannig of Germany. In ground-based operation, Hannig's instruments were characterized by rather limited resolution and throughput. Thus, it was rarely used for separation of proteins, its main application being in research with living cells.

The McDonnell Douglas apparatus was superbly engineered and performed well in the microgravity environment. This was certainly no mean achievement. Most important is their claim of greatly increased throughput, rather than high purity.

2. For the past ten to fifteen years, Dr. Thompson at the Harwell Atomic Energy Establishment in England has been developing a centrifugal electrophoresis apparatus of a radically new design, first proposed by Prof. Philpot, some 40 years ago. It is an impressive machine, for which large throughputs are claimed. It is marketed under the tradename BIOSTREAM by John Brown Limited of Portsmouth, U.K., but has become available only quite recently. As a result, its actual performance in daily usage is still largely undocumented.

3. The Recycling Isoelectric Focusing Apparatus (RIEF), developed in my laboratory under NASA's sponsorship. The RIEF was first proposed for operation in microgravity, but it proved to be quite effective in its ground-based operation. Schering Corporation and Ely Lilly Laboratories, two leading companies in the genetic engineering field, as well as Ionics, Inc., an engineering company, have already acquired the apparatus. We anticipate that its resolution may be further improved in microgravity.

A brief comparison of these instruments may be in order. The Harwell and the McDonnell Douglas instruments separate materials on the basis of differences in electrophoretic mobilities of components, this separating principle is technically known as zone electrophoresis. The RIEF apparatus separates components on the basis of differences in their isoelectric point. Moreover, the first two instruments are both adapted to continuous flow, the RIEF being a batch apparatus.

The Harwell apparatus has a very high throughput, but I suspect it has the lowest resolution of the three instruments. The RIEF apparatus is of modular design and, at least in principle, it could be scaled to any desired capacity. The McDonnell Douglas apparatus takes advantage of microgravity to achieve the desired throughput. Even so, a battery of such instruments will be required for actual commercial production.

Unfortunately, there was as yet no opportunity to compare directly the resolving power of the three instruments, which is a crucial factor. In analytical applications, isoelectric

focusing is characterized by very high resolution, and I expect that we have some advantages in this regard also in our RIEF. On the other hand, focusing imposes more drastic conditions on treated materials than continuous flow electrophoresis. Thus, the McDonnell Douglas apparatus is gentler and is applicable to a wider range of products. Of specific importance, it can separate living cells, which cannot be treated in the RIEF. In general, I expect that each of the three instruments will find its own niche, and that they should be viewed as complementary rather than competitive.

## ISOELECTRIC FOCUSING

Isoelectric focusing is a particularly powerful variant of electrophoresis in which separation is carried out in a pH gradient. The proteins migrate, i.e., "focus" to the pH region corresponding to their isoelectric point, where they become immobilized due to zero net charge. The isoelectric point of a protein is a rather characteristic parameter, accounting for the exquisite resolution obtainable. The pH gradient is established by the actual effect of the electric current on the appropriately chosen buffer.

The RIEF apparatus was designed to adapt isoelectric focusing to large scale industrial capacities. Due to the fact that proteins focus to a stationary point, a novel recycling principle could be adopted. Fluid stabilization is accomplished by a parallel array of filter elements, which assure laminarity of flow. Monofilament nylon screens of fine mesh porosity are used for this purpose. Several reports describe the details of instrument design (2) and performance (3).

We expect a substantial improvement in the resolution of the RIEF when operated in a microgravity environment. The absence of terrestrial gravity could permit the elimination of the screen elements, essential for the RIEF ground-based operation. In principle, such an apparatus would combine some of the advantages of the McDonnell Douglas apparatus with the sharpness of resolution achievable by recycling in a pH gradient.

The shuttle is potentially a vehicle for the industrialization of space. At the present time it is even more important to consider it as a unique national research facility, capable of providing specific data not obtainable otherwise. In electrophoretic separations, fluid disturbances can arise from two causes: gravity-dependent convection and gravity-independent electroosmosis. Electroosmosis is the streaming of fluid induced by the electric field itself and it is caused by the residual electric charge of the walls of the vessels. In the case of focusing, it is impossible to distinguish between these two effects in ground-based operation. In space, gravity effects will be abolished, permitting a clear assessment of the effects of electroosmosis alone.

We are presently preparing an experimental package comprising eight focusing columns integrated in a middeck locker of the shuttle orbiter. These columns, of varying internal configuration, will be filled with a mixture of two colored proteins, the red hemoglobin and the blue-stained human serum albumin. The separation of the two proteins will be recorded photographically, with pictures taken every 3 minutes over a 90 minute interval. In ground-based operation, only one of these columns permits clear focusing of the proteins, both gravity and electroosmosis being simultaneously abolished by screen elements. All the other cells fail to focus. Operation in space should provide a clear-cut answer to the cause of failure, whether gravity-dependent or gravity-independent. The results will greatly influence our design efforts for a space RIEF and we are most anxious to see the results of the experiment, scheduled to fly January 29th.



## REFERENCES

1. Office of Technology Assessment, U.S. Congress: "Impacts of Applied Genetics – Microorganisms, Plants, and Animals".
2. M. Bier and N. B. Egen in "Electrofocuss '78", (Haglund, Westerfeld and Ball, Eds.), Elsevier North Holland, New York, 1979; M. Bier, N. B. Egen, T. T. Allgyer, G. E. Twitty and R. A. Mosher in "Peptides: Structure and Biological Function", (Gross and Meienhofer, Eds.), Pierce Chemical Co., 1979; M. Bier, N. B. Egen, R. A. Mosher and G. E. Twitty in "Materials Processing in the Reduced Gravity Environment of Space", (Rindone, Ed.), Elsevier, 1982.
3. S. B. Binion, L. S. Rodkey, N. B. Egen and M. Bier, *Electrophoresis* 3, 284, 1982; M. Bier, O. A. Palusinski, R. A. Mosher and D. A. Saville, *Science* 219, 1281, 1983.

# THE ABSENCE OF CONVECTIVE STABILITY IN INCONGRUENT CRYSTAL GROWTH ON EARTH\*

by

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## ABSTRACT

It is often assumed that convection can be excluded in materials processing by avoiding horizontal temperature gradients, and employing top-heating and horizontal interfaces.

Our model calculations for vapor transport processes show that this supposition holds only for strictly congruent vapor-solid transitions. This result can be generalized to all fluid-solid phase transitions. Due to the omnipresence of impurity segregation, it is concluded that convective stability is practically unattainable in materials processing on Earth.

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# POTENTIAL UTILIZATION OF GLASS EXPERIMENTS IN SPACE

by

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## ABSTRACT

Materials Processing in Space (MPS) is not limited to the development of extraordinary materials requiring microgravity, and fabrication for the needs of space habitats. MPS also provides a unique and lucrative resource for advanced research on novel and improved materials for future Earth development and fabrication. Since about 1978 this has been recognized and implemented at MSCF and other NASA Laboratories. If and when space processing demonstrates unique product or process improvements or innovations unencumbered by gravitation-induced or container-conditioned disturbances, a basis for and encouragement of utilization on Earth may have been established. For instance, the preparation in microgravity and characterization of a composite alloy whose components would on Earth have separated into two liquids, does not just represent a new MPS material, but may stimulate Earth processing of a similar material by other means.

NASA is now making available joint venture formats which can be utilized by industry in the search for novel products and processes on Earth taking advantage of the unique features of microgravity facilities for advanced materials research at low cost to industry.

A review of present and potential microgravity studies in the area of glass science and technology suggests the utilization of NASA's resources in this sector by industry's research and development requirements.

Among these studies are:

Minimum cooling rates for containerless melting of borderline glasses in the absence of segregation and convection.

Conditions of homogeneous nucleation.

Fining mechanisms in the absence of buoyancy.

Containerless production of precursors, including gel synthesis, for wave guide materials.

Fabrication of uniform microspheres and microballoons.

Surface-active glass components.

Diffusion.

High temperature glass ceramic formation free of distribution.

Conditions for bulk metal glass fabrication.

Phase separation and microstructure.

## 1. LEVELS OF UTILIZATION

The availability of the Space Shuttle, and, eventually, of a Space Station provides a microgravity ( $10^{-6}$  to  $10^{-2}g$ ) environment for increasing periods of time. There also is an increasing availability and efficiency of astronaut intervention. As a result of this situation materials processing in space (MPS) is fast becoming a resource of potential utility to industrial as well as academic research.

A word like utilization or commercialization, when referring to MPS can easily be misinterpreted. A clear interpretation will help to assess the merit of specific experiments and proposals in this connection.

MPS can advance the state-of-the-art in various levels of achievement. Starting from direct or ultimate towards more subtle achievements these levels might be described as follows:

1. Processing materials in space use.  
(Example: Building components)
2. Processing materials in space which can not be obtained on Earth. (Example: Electrophoresis) (SNYDER 1983, p. 88) {1a}.
3. Demonstrating a novel or improved material to stimulate Earth development. (Example: Defect-free crystals).
4. Gaining knowledge to stimulate Earth research and development on novel or improved materials.  
(Example: Transport phenomena).

The most exciting but obviously limited level is level 2. Yet levels 3 and 4 deserve increasing attention by industry, since NASA is now making available joint venture formats for

industrial research towards advance materials at very low cost and with proper safeguards for proprietary areas (BROWN and ZOLLER 1981) {2}. Level 1 will fast move from fantasy land to stark reality. When the Princeton "blueprints" (slide) for a space city of 28,000 people by 1990 at a cost of 3G\$ were presented to the MPS community around 1970, I countered the skeptical reception by the majority of those present, by saying: "I'm convinced of the reality of a space station though for fewer people, a little later, at much higher cost." NASA's Hans Mark now forsees realization in the very near future.

The Soviet Union has most definitely accepted expanding human habitation outward as a formal long-range goal and considers current endeavors (such as two reusable craft, a light space plane and a heavy lift shuttle etc.) as something like intermediate steps (Office of Technology Assessment 1983) {3a}. Congressman Fuqua, Chairman of the Science and Technology Committee considers this assessment "helpful for our deliberations on Nasa's potential space station initiative." {3b}.<sup>1)</sup>

In reviewing current MPS studies in the areas of glass science and technology at this symposium we are concerned with levels 3 and 4. The scope of these studies should become more familiar to industry for potential utilization; and NASA's selection of future MPS proposals should give a modicum of consideration to this aspect side by side with their scientific quality. Industry involved in producing and using glass as a material per se and in devices has begun to pay attention to this aspect by participating in NASA sponsored conferences covering this sector (e.g., Snowbird, Utah and Bedford Springs, PA. 1983). In what follows a brief description of current projects on glass processing in space is given with this viewpoint in mind.

## 2. GLASS PROCESSING EXPERIMENTS IN SPACE

Since 1969 the MPS program was, in part, guided by advice from the University Space Research Association (USRA) - an association of now 54 universities - through its topical committees. It is worth noting that virtually all current glass experiments in space correspond with recommendations of USRA between 1970 and 1980. They include:

### 2.1 Shells

The processing in space of glass shells of exacting dimensions, sphericity and concentricity is of potential value to the production of fusion targets (WANG 1983, p. 129) {1a}. The study of fundamental properties required for this task can proceed unencumbered by the coupling on earth of time, temperature

and gravity. WANG works with metal glasses. DUNN (1983 p. 111 {la}) works with the more conventional glasses now in use, in a preflight gas jet levitation system.

## 2.2 Critical Cooling Rate and Novel Glasses

From a fundamental as well as a practical viewpoint, one of the most important and essentially unresolved questions regarding the value of glass processing in space is: whether and to which extent nucleation and growth rates, and thus the chance of obtaining novel glass systems, differ in 1G and microgravity environments. Expectations of advantages are based on the absence in microgravity of container walls, contamination, segregation and, consequently, of heterogeneous nucleation. In most cases limitations to the development of new extreme glasses are due to heterogeneous nucleation spawned at surfaces and interfaces, or by gravity-induced segregation. In fact, homogeneous nucleation characteristic of the inherent composition has been demonstrated only in rare cases. Heterogeneous nucleation often occurs at a rate of cooling orders of magnitudes higher than that for homogeneous nucleation. In the case of metal glasses this may make all the difference between obtaining or not obtaining bulk glass form for important new compositions (SPAEPEN 1983, p. 34) {lb}. The program pertaining to this problem includes amorphous silicon and has been extended to 1986. A study with similar objectives using levitation processing developed at JPL includes organic glasses (TRINH 1983, p. 35) {lb}. Ground studies on the fundamental issues governing the possibilities of obtaining bulk metal glasses (TURNBULL 1983, p. 127) {lc} do indeed encourage microgravity experiments exemplifying potential technological achievements.

As to oxide glasses the expected suppression of heterogeneous nucleation/crystallization facilitating the expansion of compositional limits for the formation of technologically desirable glasses is the major topic of preflight and flight experiments by DAY 1983 (p. 108) {la}; experiments in which I have become involved for many years.

If and when a ratio of minimum (critical) cooling rates ( $R_c$ ) has been established ( $R_c$  (Earth)/ $R_c$  micro-g), properties of technological interest are to be determined in the microgravity-produced extreme samples. The program also includes fluoride optical glasses recently devised to replace  $\text{CaF}_2$  crystals which control the secondary spectrum in optical systems (apochromats). At this point industry has to introduce some  $\text{P}_2\text{O}_5$  to prevent crystallization.

Similarly, the boundaries of glass formation in the absence of surface (or impurity-, or segregation-) induced crystallization, are of importance for the development of waveguides in the higher ( $>8\mu\text{m}$ ) wavelength infrared where scattering is minimized

permitting longer distances between relays. Promising candidates are heavy cation (e.g. Zr, Hf, Th) fluoride glasses which are now studied in a microgravity program by DOREMUS 1983, p. 31 {1b}, (see also BANSAL et al. 1983 {4}).

At Marshall Space Flight Center a ground facility using new laser heating and cooling techniques has been set up to evaluate critical cooling rates of borderline glass formers in containerless production of bulk glass samples as potential flight candidates (ETHRIDGE 1983, p. 115) {1a}, ETHRIDGE and CURRERI 1983 {5}.

Fundamental understanding of homogeneous and heterogeneous nucleation and crystallization as well as practical information pertaining to glass processing in space is the objective of a broad-based investigation at JPL (WEINBERG 1983, p. 38) {-1b}.

### 2.3 Gel Synthesis of Glasses

Both for MPS and for precursors of flight experiments the recently expanding field of low temperature glass synthesis from gels is of significant interest.

Gel synthesis avoids mechanical mixing and yields compositionally homogeneous samples which are promising candidates for flight precursors (DOWNS 1983, p. 109) {1a}. An extensive evaluation of monoliths obtained in this way for flight selection has been carried out at BATELLE in the systems  $\text{SiO}_2$ - $\text{GeO}_2$  (and  $\text{TiO}_2$ ), and  $\text{GeO}_2$ - $\text{PbO}$  (and  $\text{Bi}_2\text{O}_3$ ) (MUKHERJEE 1983, p. 119) {1a}.

The utilization of properly selected microgravity experiments based on gel synthesis of glasses should aid the development of advanced materials and processes in industry.

### 2.4 Immiscibility

In many metallic as well as non-metallic binary (and polynary) systems the phase diagram shows an above-liquidus immiscibility region. Usually two liquids one above the other are obtained in a melt. Even after stirring and fast casting an ingot contains two separate regions. In the absence of gravity two liquid phases will not so separate and a novel micro-phase-separated material may be obtained.

Such experiments are contained in the flight and pre-flight program of DAY (1983) e.g. in systems  $\text{CaO-SiO}_2$  ( $\text{B}_2\text{O}_3$ ,  $\text{GeO}_2$ ).

In the field of crystalline metal alloys new materials have, indeed, been obtained from liquids separating in 1G in a recent flight experiment. (GELLES et al. 1983) (9)

## 2.5 Surface Tension

Surface tension is an important factor in the behavior of bubbles. The behavior of gas bubbles in glasses is of interest for several reasons. One is the necessary development of mixing and fining techniques for glasses melted in a microgravity environment where convection - mobilized for this purpose under 1G - is absent. Another one is the separation of convection (buoyancy) and solution mechanisms for better understanding of the technologically important fining process in the glass industry on earth. Bubble behavior also affects microballoon formation. A very large program is under way since 1977 in this area (SUBRAMANIAN and collaborators at Clarkson. References can be found on pages 92 and 93 of Reference 1a). A fascinating aspect of these investigations is the migration of bubbles in containerless melts on the surface of which a hot spot creates a gradient in surface tension. WEINBERG in the referenced study, p. 38 {1b} also addresses bubble behavior. He, and many associates, have pioneered the problem in many earlier studies reference to which is found on pages 38 and 39 of Reference 1b.

Components decreasing the surface tension of a glass tend to enrich in the surface. This change in composition is of importance whenever the glass surface plays a decisive role (substrate, amplifier, source of reduction or crystallization). UHLMANN and TULLER 1983, p. 37 {2b} determine the compositional gradients near and at the surface under conditions undisturbed by gravity-induced convection and segregation. I am now associated with this study of a problem with which I have been involved in for some time.

## 2.6 Composites

The precise arrangement of a second phase in a composite could be obtained without interference of gravity by space processing. I am not aware at this time of any experiment underway. I understand that ZARZYCKI 1983 {6} has submitted a proposal involving metal spheres in a glass matrix with an eye on some electrotechnical application.

Similarly, glass ceramic specimens whose matrices tend to sag in 1G might be obtained in an microgravity environment.

3. Soviet glass experiments in space are listed in App. 1.

## SUMMARY

Glass processing experiments in space underway or proposed may well suggest utilization in research and/or development aiming at new or improved materials of industrial interest. Joint venture formats have been made available by NASA recently which seem advantageous for industrial participation at low cost and



with proper safeguards of proprietary rights. It is hoped that interaction of industry, academy and NASA in this sector will be encouraged and broadened as a result of the evaluation of current and proposed glass experiments and the incentives offered. Eventually, industry might initiate their own microgravity experiments using NASA facilities (RINDONE 1983) {7}.

#### REFERENCES

1. NASA Technical Memorandum <sup>a</sup>TM 82525, April 1983  
Materials Processing in Space, Program Tasks  
  
<sup>b</sup>TM 82548, October 1983  
Materials Processing in Space, Program Tasks, Supplement  
  
(Additional references are listed in these two memoranda.)
2. BROWN R, ZOLLER L. Avenues and Incentives for Commercial Use of a Low-Gravity Environment, NASA Technical Paper 1925, September 1981.
3. Office of Technology Assessment <sup>a</sup>"Salyut: Soviet Steps Toward Permanent Human Presence in Space"  
  
Technical Memorandum 003-00937-4, 1983-12-22  
  
<sup>b</sup>News Release 1983-12-22
4. BANSAL N., DOREMUS R., BRUCE A., MOYNIHAN C. J. A. Cer. Soc. 1983 66 233.
5. ETHRIDGE E., CURRERI P. Electromagnetic Moldless Casting (J. P. Wallace ed.) North Holland 1983.
6. ZARZYCKI J. Oral Comm. 1983.
7. RINDONE G. Statement before Congress Subcommittee on Space Science 14 Sept. 1983.
8. PETROVSKII G., RYUMIN V., SEMESHKIN I. Steklo i Keramika 1983 (1) 5.
9. GELLES S., MARKWORTH A., MOBLEY C. Low-Gravity Experiments on Liquid Phase Miscibility Gap (LPMG) Alloys - Materials Experiments Assembly (MEA) Proceedings of the 4th European Symposium on Materials Sciences under Microgravity. ESA SP-191, June 1983.

#### FOOTNOTES

1. Since completion of this paper the President has endorsed a USA commitment to a space station.

## APPENDIX 1

### Some Soviet Glass Experiments in Space<sup>(8)</sup>

#### 1. Surface Tension. Bubble Behavior.

Surface tension was reported to assert its influence more in microgravity than at 1 G. A glass sample was degassed reasonably (almost all bubbles brought to the surface) when an angular momentum of the "space station" was specified for 20 minutes. Bubbles in the case of a stationary condition of the sample were found migrating towards the hotter zone.

#### 2. Absence of Convection.

A zone colored blue by cobalt doping was maintained in microgravity.

#### 3. Immiscibility.

In a laser glass immiscibility was suppressed enough to allow to increase from a maximum not much above 2% to a level of 10% the amount of  $\text{Nd}_2\text{O}_3$  accepted, thus increasing efficiency. A phosphate-based optical glass (OPS 3215) was increased in radiation resistance, a result attributed to suppressed immiscibility.

#### 4. Composites.

The efficiency of a magneto-optic borate glass was reported improved by the more even distribution of the active iron oxide crystals in the matrix.

**PREPARATION OF LARGE-PARTICLE-SIZE MONODISPERSE LATEXES  
IN SPACE: THE STS-3, STS-4, STS-6, AND STS-7  
MISSION RESULTS**

by

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**ABSTRACT**

Large-particle-size monodisperse latexes were prepared on four STS missions of the Space Shuttles "Columbia" and "Challenger" using flight hardware comprising four automated 100-cm<sup>3</sup> polymerization reactors. Seven polymerizations carried out on the March 1982 STS-3 mission of the "Columbia," and the April 1983 STS-6 and June 1983 STS-7 missions of the "Challenger," gave monodisperse latexes of 5-18 $\mu$ m diameter with narrower particle size distributions than the corresponding ground-based control polymerizations. The rates of polymerization in microgravity were the same as on Earth. The results of these experiments are reviewed, and the prospects of the development of a space production process are discussed.

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\*Paper presented by J. W. Vanderhoff.

# LOW-GRAVITY SOLIDIFICATION OF CAST IRON AND SPACE TECHNOLOGY APPLICATIONS

by

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## DISCUSSION

Deere has performed a limited number of tests on the solidification of cast irons in the low-gravity environment provided by the KC-135's and the F-104 aircraft. The results today are very promising, although we have not satisfied our total curiosity about the influence of low-gravity on the graphite formation and microstructure of cast irons.

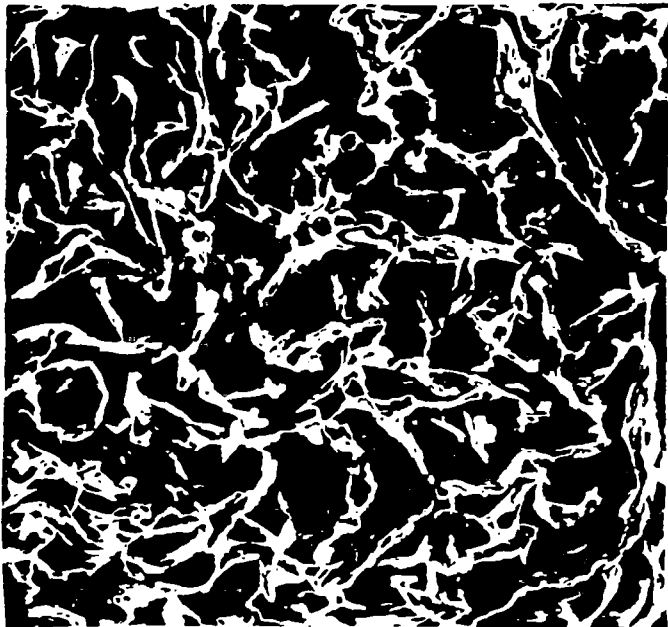
Deere is the world's largest manufacturer of farm equipment. A few of our products are: tractors, combines, tillage, planting and harvesting equipment. We also manufacture a line of industrial equipment, including earthmoving and forestry products. Included in our product line are mowers, tractors, and other lawn care equipment.

Cast irons make up about 25% by weight of our products. We have some of the largest foundries in the country outside of those operated by the automotive companies. We produce 3 grades of iron: gray iron, compact graphite and ductile iron. The table below shows the properties of these irons.

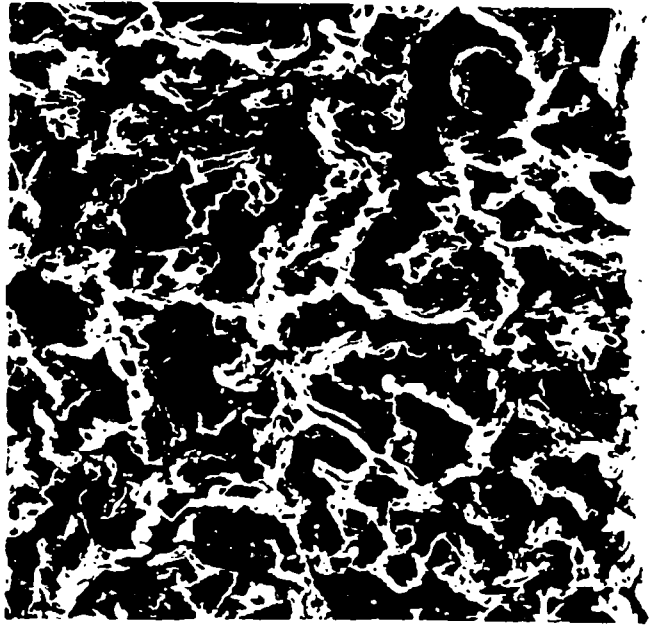
TABLE 1. DEERE CAST IRON PROPERTIES

<u>IRON TYPE</u>	<u>MIN TENSILE STRENGTH MPA</u>	<u>MEAN HARDNESS MPA</u>	<u>ELASTIC MODULUS GPA</u>	<u>THERMAL CONDUCTIVITY W/M°C</u>
GRAY	200	2100	100	48
COMPACT	300	2100	135	43
DUCTILE	550	2100	175	29

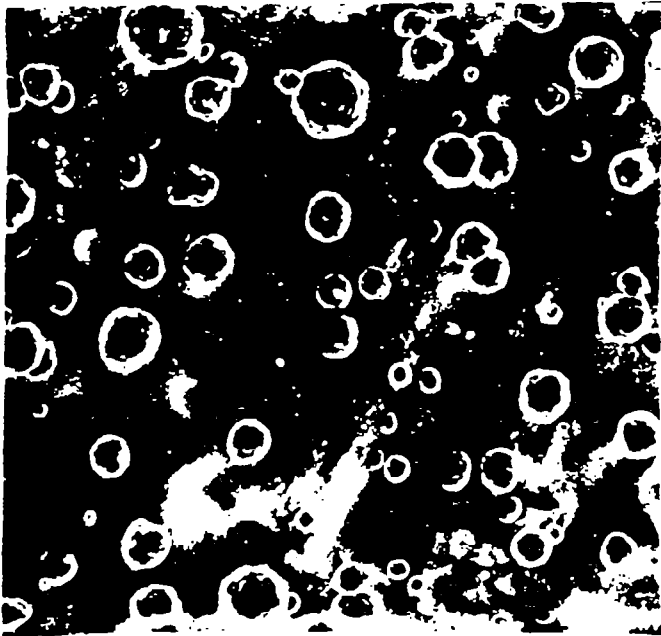
Typical microstructures of these cast irons are shown in Figure 1.



GRAY IRON



COMPACT GRAPHITE IRON



DUCTILE IRON

Figure 1. Typical microstructures of cast irons (deep etched, 200X).

Gray iron has interconnected flakes of graphite much like corn flakes in a box. Around the graphite is a matrix of metal.

Ductile iron has spheroidal graphite formations whereas compact graphite is similar to flake, but with rounded edges lowering the stress concentrations due to notches that you find in the gray iron. The gray iron, by its nature of the many notches all around the graphite flakes, is quite brittle. It exhibits little or no ductility whereas the compact graphite iron has a higher strength and exhibits some ductility and the nodular iron with the spheroidal shapes of graphite exhibits significant ductility and higher tensile strength.

Our involvement with NASA started about four years ago through the American Institute of Aeronautics and Astronautics program of visits for industrial firms to the NASA research centers. On these visits to each of the NASA research centers, we observed many things of interest to us. We also had visits by Harry Atkins and others of the Marshall Space Flight Center team on materials processing in space and by Nancy Williamson and other personnel from Rockwell International who were promoting the utilization of the shuttle. These visits revealed some of the possibilities for processing materials in space.

Shortly before these visits, we were requested by a museum to slice some meteorites. These meteorites exhibited graphite formations in basically stainless steel, very similar to the graphite formations in ductile iron. If these nodules occurred naturally in space as the meteorite cooled, what would be the influence of gravity on the graphite formations in our cast irons? This question began the discussions of conducting tests in the low-gravity environment on each type of Deere cast iron.

This was suggested to the people at Marshall Space Flight Center and we began our discussions on conducting appropriate experiments. The scientists at Marshall had developed a furnace which was deemed appropriate for melting and solidifying small cast iron samples in the KC-135 aircraft. The sample, itself, was 8 mm in diameter by 20 mm in length. It was placed in the crucible and into the insulated furnace.

At Deere we performed two types of analysis: (1) A theoretical analysis using the computer to predict the cooling versus time throughout the small test specimen. To verify the calculations and the test equipment, we conducted, in our research foundry laboratory, tests to generate a cooling time curve for the cast iron in the furnace. A typical graph is shown in Figure 2.

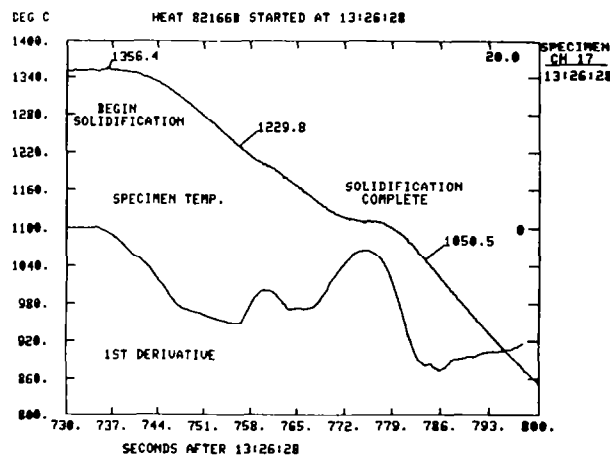


Figure 2. Cooling curve for low-gravity sample conducted in ground-based laboratory.

The objective of the test was to be able to cool the cast iron through the solidification period while the aircraft was going through a period of low-gravity. The period of low-gravity was just barely sufficient in the F-104 aircraft to solidify the iron at low-gravity. However, prior to the low-gravity period, we had a period in which the gravity was substantially over 1-g.

The initial flights were conducted on a KC-135 in which we had a period of about 30 seconds of low-gravity. We then switched our operations to the F-104 where we had a period of approximately 55 seconds of low-gravity. With the difficulty in being able to solidify the iron at exactly the right time in relationship to the low-gravity, we did see some influences on the microstructure. The results today indicate that the primary mode of graphite transport is by diffusion.

When the results of our tests, those by Bethlehem Steel in the same test program as ours and the work done by Dr. D. Stefanescu at the University of Alabama in Tuscaloosa with a directional solidification furnace, there appears to be considerable promise in continued experimentation in the solidification of cast iron at low-gravity.

We are, of course, concerned about the producibility and the cost of producing cast irons. For the sake of performance and durability, we must keep the strength level up. If we increase the hardness to obtain the strength, the tool-life during machining is low and if we try to obtain the increased strength at low hardness we then have poor castability in the foundry.

Anything that we can do to open this window would be very useful in production. Also, increasing the ability to control the process and stay within the allowable window would make the production of quality irons easier.

In studying the results obtained to date, it appears that we have three areas in which we can obtain additional information by further tests at low-gravity. These are:

### FUTURE SUBJECTS FOR LOW-GRAVITY TESTS

#### PROCESS MANAGEMENT

CARBON FLOTATION

HIGH CARBON IRON PHASE DIAGRAM

CELL SIZE CONTROL

DIFFUSION MEASUREMENT LIQUID-SOLID

QUANTIFY DIFFERENCE CAUSED BY LACK OF CONVECTION

#### DESIGN DATA

TRUE LIQUID THERMAL CONDUCTIVITY

PROPERTIES OF HIGH CARBON

#### NEW MATERIALS

These possibilities are currently under study and will require ground base tests for comparison purposes and tests to verify the functioning of low-gravity equipment. Low-gravity tests are envisioned for the F-104 and KC-135 aircraft, and also there is the possibility that the space transportation system will be required to obtain longer time periods for the low-gravity tests.

The interaction between Deere and NASA has extended over several other different subjects. For instance, our machines contain various functional elements as shown below.

### FUNCTIONAL ELEMENTS

ENGINES	MONITORS
TRANSMISSIONS	AIR CONDITIONING
HYDRAULICS	CUTTING
COOLING SYSTEMS	SEPARATION
CONTROLS	CLEANING
ELECTRONIC	STORAGE
MECHANICAL	
HYDRAULIC	

Many of these functional elements also are present in the equipment designed and used by NASA. Our machines are made up of various materials such as:

### MATERIALS

CARBON STEELS	ALUMINUM
ALLOY STEELS	COPPER
CAST STEELS	PLASTICS
CAST IRONS	COMPOSITES
POWDERED METAL	RUBBER
PLATING	PAINTS
HARD FACING	LUBRICANTS

Some of the materials are also used in NASA equipment.

In the Deere visits to NASA research centers, we observed many subjects of common interest. One was materials technology. Several areas under materials technology were observed at NASA and many of these were discussed in detail between Deere and NASA personnel as shown on the following page.



## MATERIALS TECHNOLOGY

	<u>OBSERVED AT NASA</u>	<u>DEERE/NASA DISCUSSIONS</u>
COMPOSITES	X	X
CERAMICS	X	X
ADVANCED MATERIALS IN DESIGN	X	X
ORGANIC COATINGS	X	
NON-DESTRUCTIVE TESTING	X	X
PHYSICAL METALLURGY	X	X
FRACTURE ANALYSIS	X	X
ADHESIVES	X	X

Many types of manufacturing processes are used in producing our products. The table below shows which processes were observed at NASA and also the detailed discussions between Deere and NASA personnel.

## MATERIALS PROCESSING

FOUNDRY TECHNOLOGY		
METAL PROCESSING	X	X
C.G. IRON		X
H.I.P.	X	X
DUCTILE IRON		X
HEAT TREATING		
HIGH ENERGY PROCESSES	X	X
GRAY IRON		X
WELDING	X	X

The pressure is on for increasing the utilization of technology. This is needed for the future competitiveness of the companies in this country and to maintain a reasonable level of exports to other countries.

The competition among the companies and countries producing high technology equipment is becoming more intense and we need to continue to upgrade our level of technology to maintain our competitive edge. The Third World, by necessity, is having to produce some products that formally were produced in this country and in some of the other developed

countries. The Third World is also struggling to produce their own food with substantial opportunity to increase the production of food in a number of countries.

The number of engineering graduates in this country is substantially less relative to the total population than in Japan, thus providing them with increased technological capabilities to compete with us even stronger. In the future we will need a higher quality of engineers. We must make up for the lack of numbers in the quality and depth of the engineers. We feel the use of technology, developed for the space program, should be applied to products that can improve the business climate in this country and our competitiveness with other nations.

There have been substantial benefits to Deere. These include the intellectual insights from scientists within NASA who have unique objectives substantially different than the objectives of our own in-house scientists. It also provides the means to accelerate the introduction of advanced technology.

NASA has also benefitted from this relationship through the increased interaction with scientists in another industry and the realization that the NASA technology can be applied to non-aerospace products and processes. However, there are a number of steps that can be taken both by NASA and by industry to help in the future. NASA can improve the environment for the utilization of technology. NASA, by charter, must cooperate with other nations; however, first priorities should be the needs of the industry in this country. Other nations should not be helped to gain a competitive advantage over U.S. industry.

NASA can contribute substantially to the U.S. industrial superiority through the application of the technology they develop. We, in industry, can also take some steps to help ourselves and the country. One of these is to take positive steps to find the technology NASA has available and apply it to products today. Let's jointly tell NASA what we need so they can be considered in future plans. This will aid us in obtaining more results from our tax dollars that go to the very important mission of the NASA organization.

# PRODUCING GALLIUM ARSENIDE CRYSTALS IN SPACE

by

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## ABSTRACT

The production of high quality crystals in space is a promising near-term application of microgravity processing. Gallium Arsenide is the selected material for initial commercial production because of its inherent superior electronic properties, wide range of market applications and broad base of on-going device development effort. Plausible product prices can absorb the high cost of space transportation for the initial flights provided by the Space Transportation System. The next step for bulk crystal growth, beyond the STS, will come later with the use of free flyers or a space station, where real benefits are foreseen. The use of these vehicles, together with refinement and increasing automation of space-based crystal growth "factories," will bring down costs and will support growing demands for high quality GaAs and other specialty electronic and electro-optical crystals grown in space.

## INTRODUCTION

As the demand grows for faster and larger integrated circuits, interest is intensifying in electronic materials which offer promise of surpassing the limits of silicon based semiconductor technology. Gallium arsenide (GaAs), is generating particular interest because of its inherent advantages in terms of high switching speeds, low power dissipation, temperature tolerance and radiation resistance. Also, GaAs has the advantage that it emits coherent light.

These advantages will continue to stimulate GaAs device development in the years ahead. Increasing application of GaAs semiconductor technology is to be expected in support of increasing performance demands for high speed signal and data processing, radiation hardened military systems, phased array radars, satellite communication, mainframe computers, fiber optic communications, VHSIC and VLSIC.

## GROUND-BASED METHODS OF CRYSTAL GROWTH

Commercial crystal growth is accomplished by two processes, bulk and epitaxial.

Bulk crystal growth methods can produce very large crystals, 200 pounds or more, but the process utilizes large, heavy furnaces, high temperatures (1250°C), high power (up to 300 KW) and high pressures (up to 150 atmospheres). Further, the crystals produced are plagued by imperfections and impurities. The crystal properties vary by over an order of magnitude per inch radially,

axially and azimuthally, and even so-called high-grade crystals contain  $10^{15}$  impurities and  $10^5$  vacancy sites per cubic centimeter. These imperfections degrade the electrical performance, reliability and useful life of electronic and electro-optical devices.

Epitaxial crystal growth avoids many of the problems of bulk processing. Here the crystal material is deposited layer upon layer on a crystal seed. The process achieves more uniform crystal structure but is very slow and produces only thin layers of small diameter ( $\frac{1}{8}$  inch) crystals. Typically, epitaxial crystals have been layered upon slices of bulk crystal to fabricate devices, and is not compatible with growth of bulk quantities.

Improvements in crystal growth technique for both bulk and epitaxial processes have proven very difficult to achieve. Even with silicon, a relatively simple material, improvements are still being sought after 30 years of development. The major barriers in bulk growth are in improving crystal uniformity and purity and in reducing defect density. The barriers for epitaxial growth are in scaling to larger sizes and increasing growth rate.

The primary difficulty in surmounting these barriers lies in the fact that all growth techniques involve phase transformations from liquid to solid state and therefore involve density and temperature gradients. These gradients are the source of several different complex flow processes which cause spatial and temporal fluctuations in the growth of the crystal. Particularly significant are gravity driven convection currents which create disturbances that are particularly troublesome at the crystal growth interface.

Many efforts have been made to suppress gravity driven convection currents, with only limited success. One method, developed at MIT, applies a strong magnetic field across the molten material to suppress the currents. This results in some slowing of convective flow by simulating an increase in the viscosity of the melt, but produces only p-type material. N-type or semi-insulating material has not been successfully produced by this method. Another technique employs very steep thermal gradients at the crystal growth interface. This approach has been effective in reducing stoichiometric oscillations and constitutional supercooling, but it cannot be scaled up in a gravitational environment without causing convection. Other methods are being tried and improvements are expected. However, because of the fundamental role played by gravity in fluid dynamics, improvements of Earth-based crystal growth processes are expected to be limited in scope, and concentrated mainly in structural improvements as opposed to compositional. In space, on the other hand, where the effects of gravity are all but eliminated there is promise that bulk quantities of epitaxial quality crystals can be successfully grown.

#### LIQUID PHASE ELECTROEPITAXIAL CRYSTAL GROWTH

The electroepitaxial method of crystal growth makes use of an electric current passed through the molten solution and the seed to force migration of the solute to the liquid-solid interface where growth occurs in epitaxial layers. Supersaturation takes place in the immediate vicinity of the growth interface and growth is controlled by the rate of transfer of solute, under the electric field, to the interface. This method appears particularly attractive for the processing in space of III-V crystals, such as GaAs and InP.

A major advantage is that crystals can be grown by this process far below the melting point of the compound. In the case of GaAs, crystals have been grown electroepitaxially at temperatures ranging from 800°C to 950°C. The lower temperature allows operation below the compositional instability region and reduces dissolved impurities. Also, the problem of arsenic vapor pressure is essentially eliminated.

Further, the electric current allows control of growth rate and of doping concentration. Attainable growth rates under this process are adequate to support bulk production for commercial purposes. The electroepitaxial method, in the microgravity environment, permits the controlled growth of ternary and quaternary crystals.

### THE MARKET FOR GaAs

Interest in GaAs as a desirable semiconductor material has existed over many years. As compared to Si, GaAs offers switching speeds up to 10 times faster, power consumption of only 3 to 4 percent, higher and lower temperature tolerance, higher radiation resistance - and it emits coherent light. The poor quality of available material, however, discouraged GaAs device development effort until recently. Only in the past several years have better GaAs crystals become available from improved processing techniques. As a result, development activities aimed at marketable GaAs devices have accelerated rapidly. Some market analysts are now forecasting that worldwide sales of GaAs integrated circuits will exceed 3 billion dollars by 1995 and approach 140 billion dollars by the year 2000. Important applications of GaAs devices are foreseen in support of advanced communications systems, high speed data processing, artificial intelligence, smart weapons and microwave signal processing, among others, where the special speed, power, temperature tolerance, radiation resistance and light emitting characteristics of the material will prove significant.

Space produced GaAs will cost a great deal more than that produced on Earth, primarily because of the very high cost of space transportation. Applications for this special material are expected to be limited to devices requiring the utmost in electronic performance, reliability and lifetime, and where the cost of the material will represent only a minor portion of that of the finished system. These conditions will be present in such rapidly evolving areas as satellite communications, defense communications, mainline computers, artificial intelligence, high powered lasers, wafer scale integrated circuits and various smart weapons and defense systems.

Although market demands for new materials are always difficult to predict, it is estimated that by 1990 requirements for space grown GaAs will be in the order of 30 to 50 kg. With expanding applications thereafter, and with other types of crystals being introduced to space processing. MRA expects the market to grow substantially thereafter.

## ENHANCEMENT OF CRYSTAL GROWTH BY SPACE PROCESSING

Semiconductor single crystals constitute the basic framework of solid state electronics, and their quality (chemical and structural) has been, and will continue to be, the rate determining factor in semiconductor device and system advances. Improvements in device characteristics over the years (in terms of speed, power, sensitivity, etc.) have stemmed directly from improvements of single crystal characteristics. Often, new device and system concepts have had to await needed advancements in single crystal quality and/or dimensions. The significance of crystal quality improvements made possible by space processing should be viewed in this light.

Fortunately, crystal growth experiments in space have already demonstrated the marked improvement which can be achieved by growing the crystals in a microgravity environment. Also, improved capabilities for characterizing crystals and a better understanding of the art and science of crystal growth stemming from serious laboratory research in recent years, make possible a better evaluation of the quality enhancement achievable in space as well as the expected limits of Earth processing methods.

Since no crystals have yet been grown in space using the electroepitaxial method, actual measurements of the quality attainable must await the early experiments of the MRA joint endeavor. Ground based laboratory experiments, along with analysis of results of prior experiments in space using other growth techniques, do suggest that the quality of crystals grown electroepitaxially in space will be substantially enhanced over those grown on Earth.

Particularly, it is expected that the experiments of the joint endeavor will demonstrate that bulk crystals produced electroepitaxially in space, as opposed to Earth grown crystals, will be compositionally and structurally homogeneous, striations eliminated, and the concentration of impurities and defects (of all types) greatly reduced.

Since inhomogeneities, impurities and other defects degrade electronic performance of the crystal and lead to earlier breakdown, the availability of high quality crystals from space production can lead to important advances in device performance, reliability and useful life.

### THE NASA/MRA JOINT ENDEAVOR

NASA and Microgravity Research Associates (MRA) entered their joint endeavor agreement in April 1983. The endeavor is to develop the electroepitaxial method for growing semiconductor crystals in space. GaAs is identified as the crystal material of choice for this endeavor.

The terms of the agreement specify that MRA will be responsible for developing the experiment to be flown and for providing the necessary growth furnaces and support equipment for conducting the experiments. Also, MRA is committed to commercialize the product after the completion of joint endeavor. NASA is responsible for providing seven flight opportunities without charge and for furnishing integration services. There is provision for an eighth flight if it is mutually agreed that it is needed. No exchange of funds is involved,

but NASA has access to the science resulting from the endeavor and will receive some quantities of the crystal materials produced in space. Over the series of seven flight missions, the electroepitaxial process will be verified and refined and the furnace equipment will be tested, scaled up, improved and readied for post-endeavor commercial crystal growth operations in space.

The last several flight missions of the endeavor (in the 1987-1989 time period) will produce quantities of space grown crystals sufficient for wide-scale distribution to electronic materials laboratories for their evaluation, as well as to support initial sales to users of semiconductor crystal materials.

## SPACE TRANSPORTATION SYSTEMS

The Space Shuttle is well suited to support the research and development phases of the MRA program for producing bulk quantities of high quality GaAs crystals in space. All essential services, including electrical power, heat dissipation, and provision for monitoring and control systems, are present. These services will support the growth of 15, and possibly up to 20 kilograms of GaAs crystal on flights which do not need to accommodate other significant users of electrical power. These production quantities will be sufficient for initial commercial production. As market requirements expand, however, the limited power available on the Shuttle and the relatively short duration of Shuttle missions will not be adequate to support needed production increases. By the early 1990s MRA must be looking to other space vehicles such as free flyers or a space station to accommodate its requirements for growing bulk quantities of crystals for the market. These vehicles will have greater amounts of electrical power available, and the growth process can continue over longer periods of time.

The cost of space transportation is also a major consideration. Missions aboard the Space Shuttle, where furnaces and support equipment must be carried up and down, are very expensive and will require that the finished crystal product be marketed at a price much above that of crystals produced on Earth. The cost of production aboard Shuttle-serviced free flyers or a space station, where the furnaces will remain in orbit, are expected to be considerably less. This saving can reflect in lower market price which, in turn, will stimulate market demand. However, it should be noted that regardless of which mode is used, Shuttle sortie, or Shuttle-serviced free flyer or space station, transportation costs using the Shuttle Transportation System are the dominant part of production costs. These costs, unless significantly reduced, will keep the price of space products restrictively high.

# LAND REMOTE SENSING COMMERCIALIZATION – A STATUS REPORT

by

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## ABSTRACT

This paper will describe the current offer by the United States Department of Commerce to transfer the U.S. land remote sensing program to the private sector. A Request for Proposals (RFP) was issued on January 3, 1984, soliciting offers from U.S. firms to provide a commercial land remote sensing satellite system. Proposals must be submitted by February 29, 1984, and must address a complete system including satellite, communications, and ground data processing systems. Offerors are encouraged, but not required, to propose to take over the Government Landsat system which consists of Landsat 4, launched in July 1982, and Landsat D' to be launched in the next few weeks. Also required in proposals are the market development procedures and plans to ensure that commercialization is feasible and the business will become self-supporting at the earliest possible time.

To carry out the Solicitation, the Secretary of Commerce has appointed a Source Evaluation Board for Civil Space Remote Sensing (SEB/CSRS). The SEB prepared the RFP and will evaluate responses and make a report of findings to the Secretary, who is the Source Selection Official for this Solicitation.

As a matter of Federal Policy, the Solicitation is designed to protect both national security and foreign policy considerations. In keeping with these concerns, an offeror must be a U.S. Firm. Requirements for data quality, quantity, distribution and delivery are met by current operational procedures. Any changes in data development and distribution proposed by an Offeror will require U.S. Government approval. Some additional requirements on how the commercial operator must comport itself to address national security concerns are addressed in a classified Appendix.

Cost to the Government will be a major factor in review of the proposals. Therefore, it is the Government's desire that the Offeror be prepared to develop and operate follow-on systems without Government subsidies. However, to facilitate rapid commercialization, an offeror may elect to include in his proposal mechanisms for short term government financial assistance.

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\*Paper presented by E. Larry Heacock.



## INTRODUCTION

In February 1983, the President decided to offer the United States' civil operational remote sensing satellites to the private sector for commercialization. Pursuant to that Presidential decision, the Secretary of Commerce has appointed a Source Evaluation Board for Civil Space Remote Sensing (SEB/CSRS). The SEB prepared the RFP and will evaluate responses and make a report of findings to the Secretary, who is the Source Selection Official for this Solicitation.

The objective of the Solicitation is to establish a commercial U.S. civil operational land-observing satellite program. This is being done in order to maintain U.S. leadership in remote sensing from space and to foster the economic benefits of such data for the private and public good.

The law requires that contracting for the system may not occur until: (1) The Secretary of Commerce has presented Congress a comprehensive statement of recommended policies, procedures, conditions, and limitations to which any contract should be subject; and (2) Congress thereafter enacts a law which contains such policies, procedures, conditions, and limitations as it deems appropriate.

On January 3, 1984, the Government issued a Request for Proposals (RFP) for a commercial land remote sensing satellite system. The Government is willing to provide financial and/or operational support during the early years of operation of the system, but its ultimate objective is to purchase data, over the counter, from a self sustaining commercial operation. Government financial support will be limited both as to amount and duration. In return for its support, the Government requires that the system meet certain technical and procedural requirements.

There is a fundamental difference between the present situation and that envisioned for the future. Today the government owns the satellite data. In the future, a commercial operator would own the raw data produced by the commercial satellite system. The Government would buy data from the owner/operator and further process and use the data for its own specified purposes. Offerors are required to define their proposed proprietary interests in data (including copyright) and to indicate how these interests could inhibit, limit, restrict, or alter the cost of the use of data by Federal Agencies.

While the Government expects the commercial operator to maintain his own inventory of data products for sale, the Government also expects to continue to maintain an archive of data of potential historical interest. The bidders must propose arrangements to make possible both functions.

The RFP has been structured to elicit proposals for a commercial operational land remote sensing satellite system to begin operation after the present Government Landsat system. Offerors are encouraged to include in their proposals provision for taking over the Landsat system for its lifetime.

An offeror must propose a satellite system, ground control system and data preprocessing system. Also required are the market development procedures and plans to ensure that commercialization is feasible and the business will become self supporting at the earliest possible time.

The Government is interested in innovative techniques or systems which would improve service and/or reduce cost. Thus, Offerors are encouraged to propose new technology, innovative systems or innovative business approaches which would be advantageous to the Government, to the Offeror, or to both. All reasonable business arrangements between the Offeror and the Government will be considered.

As a matter of Federal policy, this Solicitation is designed to protect both national security and foreign policy considerations. In keeping with these concerns, an offeror must be a U.S. Firm as specified in the Solicitation. The requirements for quality and quantity of data, as well as the distribution and delivery of that data to meet such considerations, are met by current operational procedures. Some additional requirements on how the commercial operator must comport himself to address national security concerns are addressed in a classified Appendix to the Solicitation. The provisions of that Appendix must be met in order for a proposal to be considered acceptable.

Because the U.S. Government is no longer likely to be the most important customer for land remote sensing data, the international specifications on how a commercial operator will do business are not strictly limited to past government practices. However, the operator is encouraged to continue with policies now used by the Federal Government vis-a-vis Landsat data. Should he wish to change this mode of operation, Government approval is required.

In general, the Source Evaluation Board has identified no need for a new regulatory scheme or authority in order to enforce the stipulations of the RFP and the resultant contract. Antitrust regulations, international trade controls, national defense reviews, communications frequency allocations and launch approvals can all be handled within present Government regulatory apparatus. Most other stipulations of the contract can be handled through normal contractual arrangements. The possible exception is that the Government may need additional authority to impose civil penalties, should a successful bidder fail to meet the national security or some of the international stipulations outlined in the RFP.

Nothing in the Solicitation is intended to limit an Offeror from pursuing other related business opportunities which are not within the scope of the Solicitation (e.g. providing specialized or "value-added" services to customers other than the Government), but no direct Government support of "value-added" services will be acceptable. Furthermore, the Government does not intend to limit itself to buying data and/or services from only the successful Offeror.

Cost to the Government over the term of the contract will be an important factor in the selection. As a baseline for a cost assessment, the Government has prepared an accounting of its assets and operating costs. This accounting is summarized in the solicitation.

## **BACKGROUND**

The Landsat satellite system provides information about the condition of the Earth's surface by a process of sensing radiation from objects on the earth. Landsat 4, launched July 16, 1982, carries a new sensor, the Thematic Mapper (TM) which, for the first time, provides 30 m data in a seven band format. To provide continuity of data with previous Landsats, the Multi-Spectral Scanner (MSS) which provides 80 m resolution in four bands was also deployed on Landsat 4. Both TM and MSS will be deployed on Landsat D'.

On November 16, 1979, the President assigned to the National Oceanic and Atmospheric Administration (NOAA) the management responsibility for civil operational land remote sensing. NOAA assumed operational control of the MSS on January 31, 1983. However, due to the experimental nature of the TM, operational status for this sensor is not planned until early 1985. The current Landsat system includes no satellites after Landsat D'.

As part of the current Administration's policy of reducing Government size and entrusting to the private sector as much of current Government functions as possible, President Reagan decided, on February 28, 1983, to offer to the U.S. private sector the opportunity to propose a commercial land remote sensing satellite system. The President's original proposal included the commercialization of the U.S. civil meteorological satellites as well as the land remote sensing spacecraft. However, as part of the fiscal year 1984 appropriations process, the Congress added language to the Department of Commerce appropriations law which had the effect of excluding the meteorological satellites from the commercialization activity.

### **CURRENT SYSTEM DESCRIPTION**

There have been four Landsat satellites launched to date. Landsat 1, 2 and 3 have ceased to function. Landsat 4 has experienced several failures including a serious reduction in available solar array power and a complete loss of the X-band direct downlink for Thematic Mapper image data. As of December 1983, sufficient power was available to operate the MSS image data mission providing direct readout at S-band to U.S. and foreign ground stations and to provide one pass of Thematic Mapper data per day when TDRSS is operational. Hardware changes have been made to Landsat D' to correct the failure modes observed in Landsat 4. Landsat D' is in test in preparation for its anticipated launch on or about March 1, 1984.

Landsat 4 and Landsat D' consist of NASA's standard Multimission Modular Spacecraft and a mission-unique instrument module. The satellite configuration is designed for a three-year mission life and can accommodate retrieval by the Space Shuttle in a near polar orbit. The spacecraft bus includes the attitude control, propulsion, communications, data handling and power subsystems. The instrument module includes the MSS, TM, a wideband communications subsystem, high-gain and other antennas, and a solar array capable of generating two kilowatts of power.

Landsat tracking, command transmission, telemetry and image data acquisition are currently performed by a NASA worldwide network of ground stations and the Transportable Ground Station at NASA's GSFC in Greenbelt, Maryland.

The current Landsat Ground Segment consists of a Control and Simulation Facility (CSF), a Mission Management Facility (MMF), an Image Generation Facility (IGF), and Direct Reception Ground Stations, including the Transportable Ground Station (TGS). The Landsat-4/D' Ground Segment and its associated "Products" are depicted pictorially in Figure 1.

The Landsat-4/D' Ground Segment operations and equipment resides in Building 28 at Goddard Space Flight Center. The Operational System completely occupies one wing of this building. Preprocessing of data is performed at GSFC to radiometrically correct all raw data and append auxiliary data from which geometrical corrections can be made at a later step of the process.

The Department of the Interior's Earth Resources Observation Systems (EROS) Data Center (EDC) in Sioux Falls, South Dakota processes and distributes Landsat data

under reimbursable arrangements with NOAA. The Center provides access to Landsat data as well as to aerial photographs acquired by the U.S. Department of the Interior, NASA and other Federal agencies. EDC's primary functions are data storage, reproduction and dissemination in response to user requests; user assistance and training; and research in techniques for manipulation of digital spatial data in cooperation with DOI and other agencies.

### **INTERNATIONAL AND FOREIGN POLICY CONSIDERATIONS.**

Establishment of a commercial Landsat program will require the private operator to address three areas: (1) conformity of private operation with applicable laws (i.e., international treaty obligations and export control legislation); (2) availability of data for international use; and (3) relations with foreign Landsat ground station operators.

In reviewing and responding to the international and foreign policy areas, bidders will need to bear in mind that specific issues and the international climate will be unknown variables during the lifetime of the contract. It is, therefore, not possible to state in advance the precise factors which the Government would deem critical in any particular request by a future private operator for approval/concurrence. In general, the Government would have to balance foreign policy considerations of the time--including maintenance of U.S. technical leadership and impact of a suggested private operator initiative upon relations with specific countries--against the objective of promoting reasonable commercial return for the private operator.

The U.S. Government presently has or is negotiating agreement with a number of foreign Landsat ground receiving stations around the world. The specific provisions of these agreements are set forth in a Memorandum of Understanding between NOAA and each foreign Landsat ground station operator. The current international Landsat ground station network has provided the U.S. and foreign station operators with measurable benefits and has enhanced U.S. prestige and foreign policy objectives in outer space, while providing U.S. agencies (NASA, NOAA) with revenues in the form of yearly access fees from the foreign ground station operators.

During the lifetime of Landsat 4/D', the commercial operator must obtain the concurrence of the U.S. Government before terminating or initiating agreements with an existing or prospective foreign ground station operator. Operators of follow-on land remote sensing systems are not required to maintain or develop foreign ground receiving stations. However, relations developed between a U.S. commercial operator of land satellites and any current or future foreign land satellite ground station operators shall be subject to appropriate supervision or oversight by the U.S. Government.

Each proposal shall include the plans and procedures to address foreign policy issues and international obligations. As a minimum, the proposal shall address when and how the proposer will provide the required notifications or requests for approval/disapproval, as well as the approach and organization for interface with foreign entities, the U.S. Government and other satellite operators. The proposal must also address plans and policies for international data sale and distribution. Offerors may, at their option, suggest ways and means by which the present international network of foreign Landsat ground receiving stations may be continued throughout the life of the contract.

## TECHNICAL PROPOSAL REQUIREMENTS

A successful Offeror will be required to design, develop and operate a land remote sensing satellite system and develop a commercially viable system for acquiring data meeting domestic, foreign and Government data needs.

Each Offeror must structure the Technical Proposal to respond to each of the requirements listed below. These requirements address the follow-on commercial system. In addition, takeover of the present Landsat 4 and D' system may be proposed. This paper provides a brief summary of the requirements for the follow-on commercial system.

### Government Data Needs

The proposal shall address the proposer's understanding of the data needs for Federal agencies and in particular:

- (a) Means of providing the required global data for both mission responsibilities and research.
- (b) Procedures for tasking of data requirements and relationships to commercial market requirements.
- (c) Methods and procedures to improve data throughput and timeliness.
- (d) Pricing procedures and ordering schedules for data delivery.
- (e) System improvements to enhance data coverage, times and areas for Federal data needs.
- (f) Plans to interface with, and utilize the results of Federal agency programs in remote sensing R&D.
- (g) Implications of proprietary interests, if any, in use and transfer of data within and among Federal agencies.
- (h) Methods and procedures to ensure that standards for data quality necessary to meet standard data processing of data disseminated to users will not be less than that maintained by the Federal operator at time of contract.

### Communications

The Offeror has the option of designing the system to use any reasonable communications system. The design must show, as a minimum, the advantages and disadvantages with attention to data coverage, effects on foreign and domestic markets, system reliability and lifetimes, cost comparisons between the selected communication system and TDRSS usage and the effect on Government land remote sensing data needs.

Offerors must discuss their requirements and procedures for obtaining access to and utilizing the frequency spectrum. As a minimum, the proposal shall provide the offerors' understanding of the issues involved, the approach, and the management organization to be utilized to assure effective coordination of frequency spectrum utilization. The proposal shall separately address these issues with regard to take-over of satellites/systems currently operated by the Government (Landsat 4 & D') and those designed and constructed by the private sector owner/operator.

### **Launch**

The proposal shall address the plans and procedures, with associated schedules, for launching land remote sensing satellite systems. The Government currently plans to discontinue Delta launches from WTR after the launch of Landsat D'. In the contemplated contract, the Government does not guarantee the availability of launch support services in the form of boosters (ELV or STS), launch pad support, tracking aircraft support, command and control support, test range support or other specialized support. However, the Government is prepared to negotiate the provision of such services on a cost reimbursement or other basis.

### **Data Base**

Proposals shall address arrangements, plans and procedures for maintaining an active commercial inventory of data products to be sold. Many options are possible pertaining to existing Landsat data archives and those yet to be acquired by the Government from Landsat 4 and D'. The Offeror must propose specific plans for establishing a commercial data inventory plus the interface to an historical archive that satisfies the Government's data needs.

The proposal shall address the Government's requirement to maintain an historical archive of remotely sensed data for research purposes and the public good. As a minimum, the proposal shall define the terms and conditions under which the owner/operator would make his commercial inventory available to the Government when found to have no further value to the owner/operator.

### **Research & Development**

The proposal shall address the needs and purpose of remote sensing data for R&D and the approach to provision of commercial data for research. Explicit reference should be made to (a) Provision of both commercial and experimental data in support of R&D activities, (b) The fact that U.S. Government will use remote sensing data from foreign satellites for R&D purposes, (c) Methods to maintain cognizance of R&D results for purposes of system or product improvements for commercial use, and (d) Interface procedures with Federal agencies having primary responsibility for aerospace R&D, including R&D related to applications of aerospace remotely sensed data.

## **U.S. GOVERNMENT OVERSIGHT AUTHORITY**

Successful operation of the follow-on commercial land observing system is a matter of great importance to the U.S. Accordingly, it is necessary that the U.S. Government have sufficient rights and authorities to ensure that the operating capabilities of this system are not compromised by error or inadvertance. Any proposal submitted in response to this RFP must address this issue in depth, including U.S. Government oversight of Contractor operations, U.S. Government authorities to prevent or correct deficiencies either technical or financial that would threaten the operational

capability of the system, and procedures to ensure the prompt and effective implementation of these authorities.

Offerors are required to propose a program for periodic Government review during that portion of system development which is supported by the Government. Proposals will contain a description of and schedule for a program to provide such visibility.

Since authorizing legislation is required before the Secretary of Commerce may make an award under this RFP, offerors will need to keep abreast of current Congressional views on commercial civil space remote sensing. For example, a draft bill on this subject was recently prepared by staff of the Committee on Science and Technology of the U.S. House of Representatives. Proposals should indicate a sensitivity to Congressional concerns by indentifying and defending procedures/requirements involving matters on which Congressional views have been expressed. Most importantly, proposals must indicate where they would require special authorizing legislation, and explain why such actions are considered necessary.

### **CONCLUSION**

The process described in this paper is unique in U.S. Federal Government history. It is the first attempt to spin-off to the private sector an entire Federal program. The SEB has attempted to strike an appropriate compromise between the Government oversight required to safeguard national interests and Federal investment, on the one hand, and a laissez faire approach to encourage private sector innovation, on the other. The next three months will bear watching to see how successful that attempt has been.

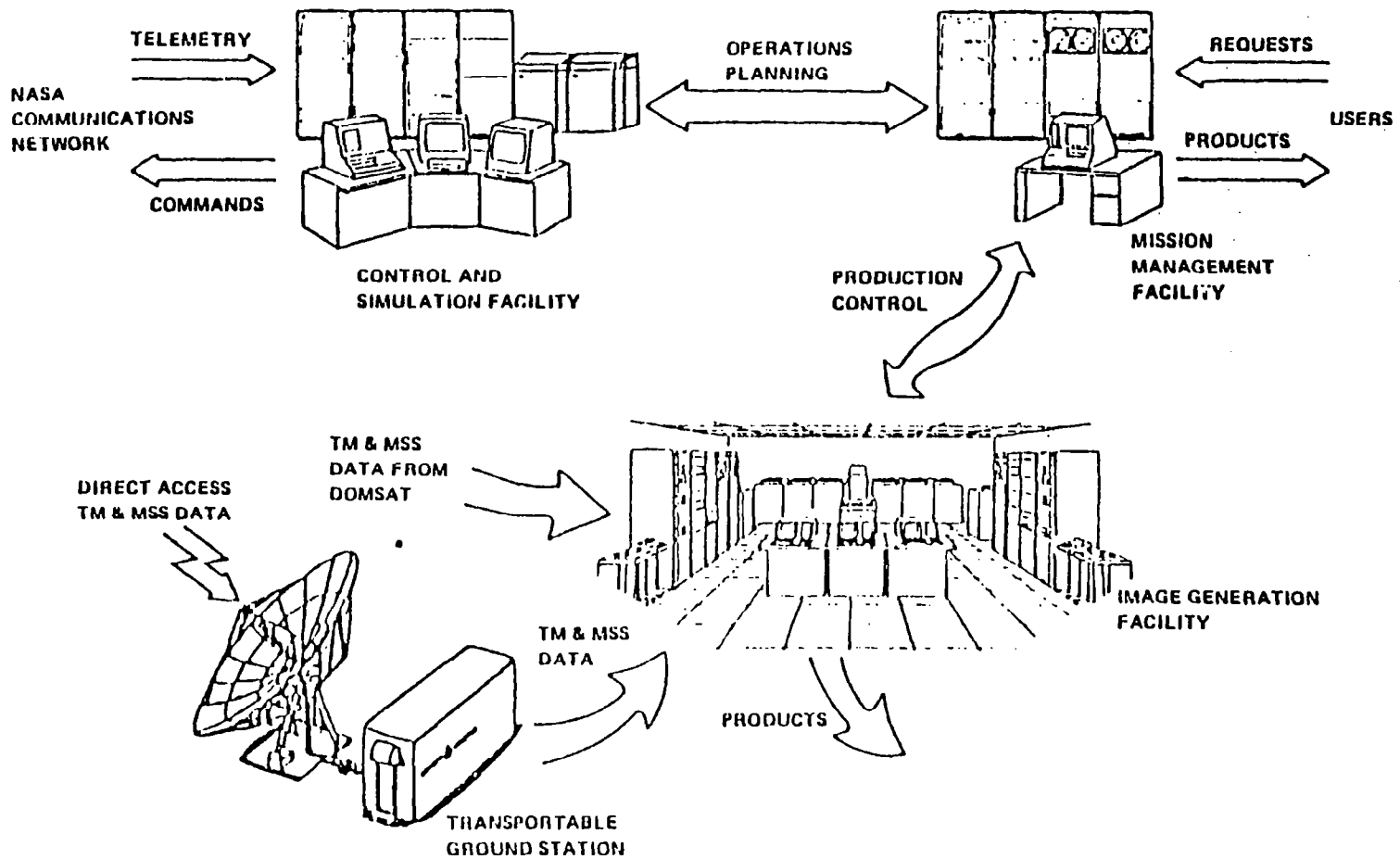


Figure 1 Landsat - 4/D' Ground Segment



# THE FUTURE OF SATELLITE REMOTE SENSING: A WORLDWIDE ASSESSMENT AND PREDICTION

by

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## ABSTRACT

The satellite remote sensing-related market promises to be very large and highly profitable for those organizations which recognize its potential. After a slow start since 1972, it appears poised to increase dramatically over the next several years. This paper provides a framework in which to assess and predict the future prospects for satellite remote sensing markets.

The scope of this paper is the satellite-related market for data, equipment, and services. It encompasses both domestic and international markets and contains an examination of the various market characteristics by market segment (e.g., Federal Government, State and Local Governments, Academic Organizations, Industrial Companies, and Individuals) and primary applications areas (e.g., Geology, Forestry, Land Resource Management, Agriculture and Cartography).

The forecasts in this paper are derived from an analysis of both U.S. and foreign market data. The paper evaluates the evolution and current status of U.S. and Foreign markets to arrive at market growth rates. Circumstances and events which are likely to affect the future market development are examined.

This paper presents a market growth scenario that is consistent with past data sales trends and takes into account the dynamic nature of the future satellite remote sensing market. Several areas of current and future business opportunities available in this market are discussed. Specific worldwide forecasts are presented in three market sectors for the period 1980-1990.

# INDUSTRIAL USE OF LAND OBSERVATION SATELLITE SYSTEMS

by

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## ABSTRACT

*The principal industrial users of land observation satellite systems are the geological industries; oil/gas, mining, and engineering/environmental companies. The primary system used is Landsat/MSS. Currently, use is also being made of the limited amounts of SKYLAB photography, SEASAT and SIR-A radar, and the new LANDSAT/TM data available.*

*Although considered experimental, Landsat data is now used operationally by several hundred exploration and engineering companies worldwide as a vastly improved geological mapping tool to help direct more expensive geophysical and drilling phases, leading to more efficient decision-making and results. Thus, Landsat data has no real value in itself, but in the utility of the information derived.*

*Future needs include global Landsat/TM; higher spatial resolution; stereo and radar; improved data handling, processing distribution and archiving systems, and integrated geographical information systems (GIS). For a promising future, governments must provide overall continuity (government and/or private sector) of such systems, insure continued government R&D, and commit to operating internationally under the civil "Open Skies" policy. If this is done, land observational systems will become integral features of developing U.S. and other nations' space station programs.*

## INDUSTRIAL USERS

*The principal industrial users of land observation satellite systems are the geological industries; the oil/gas companies, mining companies, engineering and environmental companies. In some respects, this is paradoxical in that the major civil system, Landsat, was principally designed for use in agriculture, hydrology, and land use planning. The potential of geological use of digital landsat multispectral scanner (MSS) type data was not well appreciated by the geological community during the design phase of the Landsat program. However, industrial geologists soon recognized the inherent capabilities to improve regional geological mapping on a global basis of data derived from the Landsat system when utilized with modern computer techniques. The principal usefulness of Landsat-type data for geological application is the increased capability to recognize large earth features*

through greater synoptic perspective and the development of an internally consistent worldwide digital data base which, if wisdom prevails, will be properly archived and thus accessible to the user community for many years to come. This is vital for the geological community as geological processes are long-term. Large scale exploration efforts include long-term, multi-country, multi-season, multi-exploration model designed programs under the effects of ever changing economic commodity cycles. The bottom line for the geological industries' use of Landsat and other satellite data is its growing usefulness in increasing the efficiency of regional geological mapping for exploration, engineering, and environmental applications.

Worldwide, the geological discipline exceeds others in the use of civil land observational satellite systems. In the United States, industrial geological use of Landsat MSS and, to a lesser extent, SEASAT and SIR-A radar and Landsat/Thematic Mapper (TM) data represents about 33% of data purchased from the EROS Data Center. To this, however, must be added non-U.S. purchases by industrial and governmental users for geological purposes. U.S. geological exploration and engineering companies operate totally separately from the U.S. government, and generally in a non-cooperative, adversarial, "hands-off" relationship; however, most other industrial and particularly non-industrial countries coordinate or merge their government/industrial non-renewable resource requirements, policies, and exploration programs. Thus, the geological use of civil land observational remote sensing satellite systems approaches or exceeds 50% of all such data use worldwide.

Several levels of sophistication of data use exist within the geological industries. In 1976, eight companies had invested in in-house data processing capabilities for Landsat and other satellite data; currently there are about 80 companies worldwide who have made such an investment. Several hundred other companies have begun using Landsat data processed by the value-added service companies and/or government data/product distribution centers, such as the EROS Data Center (EDC) in the U.S., Canada's CCRS, Australia's CSIRO, RESTEC in Japan, Spot Image in France, and others.

#### DATA USED

The principal data used to date is Landsat Multispectral Scanner (MSS) data. Use of Skylab and Salyut visible and color film, SEASAT and SIR-A radar, and Landsat/Thematic Mapper (TM) is less extensive because of the limited access to such data. Future use of radar, SPOT, and especially Landsat/TM data by the geological community will be extensive when such data becomes generally available worldwide.

Future use of civil land observational satellite data will be highly dependent on the successful development of a strong, multi-level, value-added industry. Users of these data will always have differing requirements for data products. Some users will require only low cost film products, such as standard false color composite Landsat imagery. Others will require only Computer Compatible Tape (CCT) format data for their in-house data processing systems. However, many other users will require various project oriented, processed and/or interpreted data products provided by the value-added service industry. This industry will also provide significant amounts of derived proprietary information to the exploration community on a high price and/or participatory basis.

The development of a strong multi-level value-added industry is paramount to the development of a commercial market for a U.S. civil land observational satellite system. Both will be dependent on the existence of an extensive cooperative network of worldwide ground receiving stations capable of acquiring and archiving, processing and distributing Landsat, SPOT, and other satellite data under an international "Open Skies" policy of non-exclusive, timely access to basic data at an equitable cost.

#### HOW DATA IS USED

Historically, Skylab and Landsat data were initially treated as glorified aerial photography. The geological use of aerial photography with visible and color infrared film began in earnest in the 1920's. Even today, it is a rare geologist who does not use available aerial photography in his field work. Such photography allows an overview of the geology which assists the geologist in mapping on the ground. It 'tells him' where to go to do his job efficiently. It allows him to better see the forest while mapping the trees. Satellite data, such as that derived from the Landsat system, allows the geologist to map even more efficiently than does aerial photography over much larger regions. In addition, Landsat data being digital can therefore be merged with other geophysical, geological, and geographical data sets, and contains more derivable information than does film data. This is especially true for the increased spectral information from the Landsat/TM shortwave infrared bands. The Thematic Mapper increases the geologist's ability to discriminate rocks and soil minerals from satellite data more efficiently than by standard field sampling and mapping techniques.

To extract the maximum information available in Landsat data requires access to interactive computer capabilities and to basic field work. Satellite data and the information derived therefrom can greatly assist the geologist in organizing and implementing field mapping. However, only by interacting with field validation can the maximum information content of Landsat and other satellite data be obtained.

For example, in the joint NASA-Geosat Test Case Program field study over ASARCO's Silver Bell, Arizona porphyry copper deposit, Landsat and airborne Thematic Mapper (ATM) was acquired and evaluated. Basic empirical algorithms designed to locate iron oxide (MSS-type data) and clay alteration (TM-type shortwave infrared data) were used to outline the main zone of alteration and mineralization containing the economic copper ore body. This application of the ATM system (equivalent to the Landsat/TM spectral bands) was accomplished in less than 1/1000 of the time it took ASARCO to map the zone in the field using standard techniques.

This basic but simple application can be greatly improved by 'ground truthing' in the field by making actual ground field spectrometer measurements of specific rock, soil, alteration, and mineralization areas of specific interest. The original data is further processed with ground measured radiance values and the data is reprocessed to produce more detailed imagery. In the Silver Bell example, the field verification and further enhancement produced imagery which accurately discriminated and mapped 19 different rock, soil, alteration, and mineralization areas from the original simple iron oxide/clay alteration imagery.

*In addition, Landsat digital data is operationally integrated or merged with other digital geophysical, geochemical, geological, and geographical data. The "Geocoded Information Systems" (GIS's) stack various digital information bases in order to mutually enhance the information and interpretation potential of the individual data bases. For example, a Geosat member oil company recently merged enhanced Landsat data with digitized analog synthetic aperture radar (SEASAT SIR-A data) and gravity mapping in a unique and rapid location of a successful discovery oil well in a generally difficult and commonly cloud-covered area of Indonesia. Individually, these data were not definitive as to the location of the oil producing geologic structure, but when combined, the structure was easily discernable and a successful discovery well drilled under otherwise difficult circumstances. It is important to understand that Landsat data was used as but one of several data information tools that led to the high-risk decision to drill what turned out to be an oil discovery.*

*In such applications, Landsat and other satellite data are used most efficiently in poorly known areas by looking for large geological structures that might contain energy or mineral resources. Similarly, it is used in large scale engineering projects. Once exploration prospects or engineering projects are identified, they become site-specific and airborne and surface field techniques are utilized prior to ultimate drilling decisions. However, in many international exploration and engineering programs, Landsat and other satellite data are widely used for logistical field support and program planning. Some examples are the use of Landsat to monitor sand dune encroachment on desert drilling operations, the use of radar and Landsat data to monitor sea-ice and weather conditions affecting offshore exploration and oil company sea transport, the use of Landsat spectral bands' water penetration to map offshore coastal bathymetry to plan safe and efficient marine seismic exploration, and the use of Landsat in pipeline routing and environmental monitoring of surface mining land reclamation.*

*The cost of utilizing Landsat and other satellite data varies with the degree of sophistication of the data user. Of the 80 companies who presently have in-house data processing capabilities used for geological applications, 58 are members of The Geosat Committee. In general, these systems cost \$1-2 million to establish. In 1983, a poor exploration year financially speaking, the average Geosat Committee member company budgeted \$1.2 million to operate their system, with 8-10 people directly employed.*

*In addition to the marked increase in the number of exploration and engineering companies with in-house Landsat digital data processing capabilities during the last seven years (from 8 to 80), the management acceptance of this new exploration technology is rapidly developing. Whereas most of the Corporate Members of The Geosat Committee were either establishing the systems or using them in a research and development mode in 1980, today almost all of their Landsat application activities are directed towards and funded by active field exploration and engineering regional and project groups throughout their corporate organizations.*

*In evaluating the use of civil land observation satellite systems, it is important to remember that the data itself has no intrinsic value. It is literally the proprietary 'value' of the information enhanced or derived from the basic Landsat data as it can be integrated into successful exploration or engineering programs that is operationally supported by management. Usually,*

management positively evaluates the use of such data and the information derived therefrom in terms of cost savings through increased efficiencies of geological mapping and logistic applications as part of total exploration or engineering operations.

An example is the successful use of Landsat data over Venezuela by the Bechtel Corporation. Bechtel's client required the location of a deep water port as a part of a large construction project. Standard engineering practice called for a bathymetric survey of 100 kilometers of the Venezuelan coast. The minimum bid was \$150,000; however, use of Bechtel's then newly installed Landsat processing capability produced an offshore map of shallow and deep water areas which assisted in determining a suitable port site. The use of Landsat data and the subsequent on-site verification of the near-shore deep water cost about \$10,000, resulting in a savings of about \$140,000 for Bechtel's client.

#### FUTURE REQUIREMENTS

For the future, the exploration and engineering communities will, as will the industrial agricultural community, require continuation of the present Landsat/Thematic Mapper program to acquire this vital spectral data set on a worldwide basis. The acquisition of such a data base will probably require the equivalent of at least two or more Landsat/TM-type systems past the presently orbiting and ailing LANDSAT-4. There are also requirements for higher spatial resolution (10-20 meter) and Landsat compatible digital stereoscopic data which will hopefully be provided by the French SPOT system in 1985 and the Japanese JERS system in 1990. Global Synthetic Aperture Radar (SAR) requirements will hopefully be met by the European Space Agency's ERS-1 in 1987, and by Canada's RADARSAT and the Japanese JERS-1 in the 1990's.

Equally important as the development of satellites and space sensors is the need for additional and improved ground receiving station capabilities coupled with improved computer capabilities for handling the increased amounts of digital data produced by these new satellite systems.

With respect to the U.S. government role in the future of industrial use of civil observational satellite systems, several decisions need to be made as soon as possible. The U.S. government must recognize its responsibility to commit to a continued U.S. system whether or not such a system can be successfully commercialized in this decade. The government must also recognize its responsibility to continue to support high-risk exploratory research and development in satellite remote sensing technology. Perhaps most importantly, it must continue its worldwide leadership in maintaining the international acceptance of the "Open Skies" policy for non-discriminatory access to basic data throughout the world. The alternative is resource intelligence competition and international chaos.

If the U.S. and other free world governments maintain these civil land observational satellite system policies, the outlook for their further industrial use is most promising. If the development of the use of these data is continued, then they will undoubtedly become an operational application of future U.S. and other space stations.

## SPACE AMERICA'S COMMERCIAL SPACE PROGRAM

by

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### ABSTRACT

Space America has prepared a private sector land observing space system which includes a sensor system with eight spectral channels configured for stereoscopic data acquisition of four stereo pairs, a spacecraft bus with active three-axis stabilization, a ground station for data acquisition, preprocessing and retransmission. The land observing system is a component of Space America's "end-to-end" system for Earth resources management, monitoring and exploration.

In the context of the Federal Government's program of commercialization of the US land remote sensing program, Space America's space system is characteristic of US industry's use of advanced technology and of commercial, entrepreneurial management. Well before the issuance of the "Request for Proposals for Transfer of the United States Land Remote Sensing Program to the Private Sector" by the US Department of Commerce, Space Services, Inc., the managing venturer of Space America, used private funds to develop and manage its sub-orbital launch of its Conestoga launch vehicle. Space America has been equally innovative in the development of space systems, information processing systems and its approach to resource management. It is this type of thrust, in cooperation with government, which will allow US industry to continue the national lead in space technology and services.

# LANDSAT DATA AND INTERACTIVE COMPUTER MAPPING

by

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## ABSTRACT

A large amount of earth resource data currently resides on maps. Efforts are underway in diverse environments to convert this data to digital form. The basic techniques used include manual digitizing and automatic scanning. In both cases, the data capture process is typically more than one generation away from the original source, and that inevitably entails some degradation of the data. However, original source data can be acquired without the degradation associated with conversion from existing maps. LANDSAT data is such a source.

LANDSAT data is a valuable source of original earth resource observations. Its abundant supply has stimulated its use in many diverse applications. Increasing numbers of resource professionals are compiling and analyzing data derived from satellite imagery; included are agronomists, archaeologists, cartographers, engineers, foresters, geographers, geologists, geophysicists, meteorologists, oceanographers, planners and others. The demand for interpreted image data is growing. Such data has great potential as input to Geographic Information Systems (GIS).

The tools for processing LANDSAT data are becoming more responsive. The opportunity to quickly view the results of processing is important so as not to interrupt the workflow and thought process of the resource professional. Also important is the linkage of processed imagery to descriptive data. Interactive computer mapping can provide these capabilities and more.

## BACKGROUND

The application of computers to mapping has evolved over a period of more than thirty years. The evolution can be divided into three parts: 1) 1950-65; 2) 1965-75; and 3) 1975-present.



During the first period, 1950-65, computers were seldom dedicated to any one particular application such as mapping. They were generally used for data processing. Emphasis was on solving numerical problems in batch mode. Computer mapping was slow and the graphic quality of output was poor. The delay between input, processing, and output interrupted the workflow; and editing delayed the process further. Significantly, observations from space began during this period.

During the second period, 1965-75, computer mapping began to slowly move out of the passive phase of batch mode processing. Electronic devices for displaying graphics improved, and minicomputers made mapping-specific systems more economical. The graphics-using community refined its taste and level of expectation toward computers. Some of the first functional computer mapping systems were configured for interactive mapping during this period. Also, remote sensing from space became established, and image processing emerged.

During the most recent period, 1975-present, interactive computer mapping gained acceptance. Computer equipment became less expensive and more powerful. Price declined as performance improved. Systems became easier to operate, and programming specific to mapping improved in functionality and availability. Research and development continued in image processing.

This paper will continue by expanding on three subjects: 1) Remote Sensing and Image Processing; 2) Interactive Map Compilation; and 3) Integrated Geographic Information Systems.

#### REMOTE SENSING AND IMAGE PROCESSING

For the purpose of this paper, the discussion of satellite image analysis will be restricted to techniques applied to Multi-Spectral Scanned (MSS) data collected by LANDSAT.

There are a number of things that the analyst is concerned with when processing satellite imagery; included are the spectral (color), spatial (size and shape), and temporal (rate of change) characteristics of a LANDSAT scene. Tone, texture, and context are also of interest. A basic premise is that different features of the earth's surface have distinguishable spectral signatures. It is also known that different features of the earth's surface come in different shapes and sizes. And, since LANDSAT scans the entire surface of the earth every 18 days, we can monitor conditions that change with time.

LANDSAT data is readily available to the private as well as public sector. Applications include wood supply studies, crop yield forecasts, soil moisture and erosion studies, water quality assessment, drainage studies, land use and route planning, energy and mineral exploration, and evaluation of damage from insects, fires, disease, and storms.

Except for the Thematic Mapper (TM), which is no longer sending back signals, LANDSAT scanners record energy reflected from the earth's surface in four spectral bands. Each LANDSAT scene covers about 185 square kilometers, and each scene can be broken down into pixels that are roughly 80 square meters each. The pixel resolution of the TM scanner was about 30 square meters, and seven spectral bands were recorded for each pixel instead of the usual four.

Locational data extractable from LANDSAT images meet U.S. Geological Survey mapping standards at 1:250,000. One of the main requirements for effective use of satellite imagery is the ability to locate the area of interest in terms of accurate geographic coordinates.

To accurately represent the earth's surface, LANDSAT imagery requires several types of correction. Geometric correction is needed to register the image to geographic coordinates. Also, since six scan lines are obtained in each scanning sweep, and each scan line is recorded by a different detector for each band, radiometric corrections are necessary to adjust output from the detectors to some standard. In addition, haze correction is needed to reduce atmospheric scattering, and solar illumination correction to adjust for the average brightness across an entire scene.

The bandwidths on LANDSAT imagery were selected for their specific information content. Reflected energy in the green band (500-600 nanometers) gives data on the density and vigor of vegetational cover, sediment loads in water, soil contrasts, snow cover, and sea-ice. The red band (600-700 nanometers) is suitable for distinguishing landforms, geologic structures, cultural features, drainage patterns, and land use. The reflective infrared bands (700-800 and 800-1100 nanometers) are useful for vegetation classification, wetland and flood delineation, urban area delineation, water pollution detection, and plant disease determination.

Traditionally, a number of analog and digital techniques have been employed to make effective use of the spectral data from LANDSAT's repetitive coverage. The techniques are to enhance and/or classify subtle variations in the imagery that otherwise would go unnoticed.

Analog techniques include image projection through filters and color enhancement (film density slicing). Film densities control the proportion of light transmitted through colored filters or are converted to equivalent voltages and used as input to the color guns of a video display system. Quantitative digital values are not necessarily employed with these techniques. The main drawbacks are that the film is one generation away from the source and a priori knowledge of which filter combinations will work best on which spectral regions is not always available; much time can be spent registering images and creating composites.

Digital techniques are most relevant to interactive computer mapping systems. They are either supervised or unsupervised. The technique used depends on whether the analyst chooses to input known information (a priori knowledge) or let the statistical relationship of the data determine the classification.

Supervised classification requires a priori knowledge. Training sets comprised of known features for a given area are identified by the analyst. The computer is trained to recognize each known feature (such as pine forest) based on the associated spectral value which can be identified. The computer can then search the entire image area for features having the same spectral values and classify them into groups which can be assigned a distinguishing color for display purposes. Interactive response is highly desirable for supervised classification. The quicker the response, the more subtle features the analyst can seek. A minimum of computer knowledge should not detract from the analyst's pursuit of distinguishable data.

Unsupervised classification assumes no a priori knowledge of the items to be classified. The analyst must specify several statistical parameters, usually on a trial and error basis. The total population of data is inspected by the computer for relationships based on the statistical parameters and classified into similar groupings. Clusters can be formed either by progressive division of the total data set, or by building groups through progressive addition. The analyst must then examine the groupings for some known information in the area of coverage and identify each class. This also represents an interactive requirement.

In addition to the image classification techniques already discussed, there is a requirement for image enhancement routines. Such routines are mainly used to boost an image so that the human analyst may be able to discern a greater amount of information from the image data than otherwise possible. Spectral techniques, for example, can be used to bring out the appropriate contrast in a LANDSAT image, preferably in real-time.

Sometimes, the size, shape, and orientation of objects in an image are as important as the spectral characteristics. In geology, for example, spatial criteria is critical for enhancing linear features such as faults, and circular features such as salt domes. Locating such features on enhanced images takes a skilled analyst. With enhancement techniques, the analyst combines visual inspection and computer-aided processing to extract the data inherent in an image.

Clearly the commercial processing of LANDSAT data has taken root. All of the major oil companies, along with most large forest resource companies, have capabilities of processing LANDSAT data. The growth of commercial applications will be stimulated by the integration of image processing capabilities with interactive computer mapping systems.

### INTERACTIVE MAP COMPILATION

Map compilation is performed by surveyors, photogrammetrists, remote sensing specialists, and cartographers who gather, convert, and integrate data with a variety of tools and techniques. Interactivity is the quick response of the computer to operator demands.

The collection, or gathering, of data relies on either existing base materials or original surveys, and sometimes both. Existing maps and documents can serve as the foundation upon which other information is built; or, information can be derived from existing materials to build a new base. Original surveys provide source data suitable for building new base maps and compiling overlay information. Included are land surveys, aerial surveys, seismic surveys, satellite surveys, demographic surveys, and others.

Once data has been collected in some form, the next step is conversion, or data capture. If the source data is already in some type of digital or analog format, it must be translated into the system being used. For land survey data, standard coordinate geometry can be used to build a digital file. Coordinates can be keyed-in from survey notes or legal descriptions, or entered from an electronic measuring device, such as an electronic theodolite. A stereodigitizing interface can be used to compile planimetric and topographic details from aerial photographs. Existing maps can be digitized automatically using laser scanning technology, or digitized manually using an electronic cursor device on a digitizing table. Satellite imagery can be classified to recognize different earth characteristics. An important conversion requirement is the feature coding of map and related data as it is entered into a data base.

After conversion, and sometimes during, map data must be integrated into a common, consistent format for easy retrieval and maintenance. Different scales and projections may need to be brought to a common ground for merging with other map coverage. A continuous base map with a wide area of coverage and large-scale accuracy can be created and maintained. Maps on materials with unstable physical properties can be distorted by changing humidity conditions. Mathematical fitting routines need to be used to correlate data from such distorted sources with known coordinates on dimensionally stable media. Also, aerial photographs and satellite images need to be adjusted for distortions inherent in flat representations of the earth's curved, irregular surface.

One missing component of most interactive computer mapping systems is the ability to process satellite image data. However, with raster display technologies being perfected for vector graphics, the opportunity currently exists to integrate vector data with raster imagery. In fact, a capability has been demonstrated between Intergraph and some of the leading image processing firms for converting Intergraph compiled vectors to grid data and overlaying on raster imagery to perform interactive edits. The next step is to perfect some automatic image enhancement and classification routines on the integrated systems.

It is now appropriate to begin a discussion of integrated Geographic Information Systems (GIS).

## INTEGRATED GEOGRAPHIC INFORMATION SYSTEMS

Geographic Information Systems (GIS) emerged during the late 1960s and became firmly established during the 1970s. GIS represents a multidiscipline approach to describing the spatial characteristics of data innate to a geographic area for resource planning and management purposes. Point, linear, area, and attribute data are all integrated into GIS.

A need exists to improve the input to Geographic Information Systems. GIS data bases are fairly expensive to establish and maintain. Remotely sensed images offer a way to help establish and maintain these data bases. In turn, GIS vector data acquired from other sources can be used to help classify imagery. The integration of earthbound studies and surveys with space observations is highly desirable.

Until recently, the processing of LANDSAT data has gone on largely independent of GIS endeavors which typically took place on interactive computer mapping systems. GIS requirements usually include interactive map compilation capabilities, polygon and grid data processing, digital terrain

modeling, and dynamic linkages between map graphics and descriptive nongraphic information. The dual data base concept is very important for a number of reasons. For one thing, maintaining a nongraphic file independently keeps the graphic file lean; and yet, the linkages can be maintained to allow dynamic cycling back and forth between the map and the descriptive information. For example, a set of soil polygons can be defined for an area; all the relevant characteristics of the various soil types can be loaded into a nongraphic file for quick retrieval based on the selection of the relevant polygon. The descriptive data also should allow automatic resymbolization of the graphics at different scales. This integrated dual data base approach is fundamental to Geographic Information Systems.

Some of the key areas for the application of an integrated GIS approach include agriculture, forestry, and energy exploration on a global scale. Also, the planning phase of large civil engineering projects will benefit from the application of integrated GIS capabilities.

#### SUMMARY

The integration of image processing capabilities with interactive computer mapping systems is feasible. The accomplishment of this integration will result in powerful new Geographic Information Systems. These systems will enhance the applications of LANDSAT and other types of remotely sensed data in solving problems in the resource planning and management domain, both public and private.

# AGRIBUSINESS AND SPACE – NO LIMITS TO GROWTH

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## ABSTRACT

As with most other human endeavors related to resources, agriculture has continued to ride an exponential growth curve. Expanding population and increasing demand for better diets have required the growth, and technological innovations have provided the ability to utilize available arable land more efficiently. With several notable exceptions, the response to food needs has been met by individual and commercial interests: agribusiness. Commercial applications of research have provided much of the innovation.

The World Food Problem, once considered mankind's highest priority problem, is still with us. It has become increasingly evident, however, that the problem is not presently primarily related to a shortfall of total global production. If research-driven innovation declined prior to a reduction in global population growth rate, production would become the key issue. Currently, the food problem occurs in many regions due to war, political strife, unbalanced economic conditions, unanticipated weather shifts, and lack of education and adequate communications.

Agribusiness technology has become more space-related in recent years. Although crops forecasting and improvements in yield ("the green revolution") were developed prior to the space era, it would be unthinkable today to ignore the contributions of operational meteorological and communications satellites and experimental Earth observation satellites in agribusiness. Space-driven communications now permit national agribusiness database management networks, with a significant portion of the data being space-derived. In demonstration experiments, space communications have already been shown to improve those aspects of the food problem related to education and communications.

The higher cost of energy has already had some effect on agribusiness, and this factor will require further research and fine-tuning in the near future. Space-driven energy research is of direct concern to agribusiness. Energy cost tracking is now another factor in the agribusiness computer models in use.

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\*Paper presented by Oscar L. Montgomery.

## I. AGRICULTURAL ADVANCES

Agriculture is about 10,000 years old, yet the beneficial effect that it has had on mankind and civilization is several order of magnitude greater than the use of fire or other major pre-agriculture human innovations.

Agricultural production in the United States of America has been the greatest farming industry in the world. Since 1940 Agriculture has continued to increase exponentially at an annual percentage rate of 1.3. Past experience clearly demonstrates that U.S. Agriculture is a dynamic industry utilizing new technology in its production and processing, marketing and innovating product lines. The achievements in agribusiness are phenomenal. Plant breeding has brought us improved plant varieties such as the hybrid corn and dwarf wheat; improvements in photosynthetic efficiency, nitrogen fixation and use, multiple cropping systems, protoplasmic hybrids while adding emphasis to neglected but regionally imported crops. Soil research has brought improvement in the conservation, preservation and management of soils, thus leading to the expansion of crop average at a higher cost level, and better management of tropical soils as well as increased efficiency in the use of water and fertilizers. In animal research, the knowledge of nutritionally balanced diets for livestock and poultry increased productivity significantly. Research-based technology has led us to expand the use of chemistry in agriculture, leading to the development of families of agricultural chemicals that are making it possible for farmers to control insects and diseases and maintain soil fertility.

Agricultural research has resulted in developments in agriculture products which are in part satisfying the demands for improved human diets, particularly for our neighbors in developing countries.

People need both quantity (calories) and quality (proteins, vitamins, and minerals) in their daily food intake. During the decade between 1970 and 1980 world food production kept pace with population growth in some years but not in others. At the start of 1984, approximately 400 million people were starving. One out of every three people in the world today lives in a country that cannot produce enough food or afford to buy enough from another nation to feed itself. Nearly 70 percent of these people live in the four countries of India, Bangladesh, Pakistan, and Indonesia, with the rest in Africa and Latin America.

Agricultural research and education are probing new thresholds in areas such as genetic engineering and biotechnological innovations that touch on nearly every aspect of our food and fiber system. This kind of research moves us ever closer than the realization of the second green revolution.

Just as for all great industries, agriculture must accommodate changing conditions. In anticipation of these changes U.S. Agribusiness must build new developments into the basic structure of the agribusiness industry so as to retain its productive capacity and competitive position in the world market place.

## II. THE WORLD FOOD PROBLEM IN PERSPECTIVE

When the space program was still awaiting the first orbital missions dedicated to study of the Earth's resources — in the mid-1960's — one factor often quoted was the World Food Problem. Rarely was energy mentioned as a problem. One book of that period was even



entitled, Famine—1975! [1]. The President's Science Advisory Committee produced a 3-volume report of over a thousand pages in 1967: The World Food Problem [2]. One prominent author proposed an adaptation of the military battlefield policy of "triage", whereby food aid would be denied certain nations with "hopeless" famine conditions. The State Department's Agency for International Development titled its monthly publication War On Hunger (later renamed Agenda, and now Horizons). There is little question that hunger remains a major problem on a global basis, and although still argued by U.S. political figures, it remains a problem for certain groups even in this nation of monumental food surpluses.

The model suggested by the last comment is perhaps closer to the global reality than most politicians would be willing to admit. The model, represented quite well in this state and this region, is one of sufficient food supply, but of severe problems in distribution. Those who blame hunger on overpopulation should observe that the undernourished regions of this state are also those with declining populations and population densities.

Placing the blame on population has been popular since the publication of a treatise on population by Thomas Malthus in 1798. Malthus altered his views later, but the Neo-Malthusian view has revived the pessimism, especially in such studies as those sponsored by the Club of Rome (The Limits to Growth [3], and World Dynamics [4]) and the Carter administration (Global 2000 [5]). We do not wish to imply that overpopulation is not a problem, we applaud the efforts of medical science and groups such as Planned Parenthood whereby all newborn persons are lovingly welcomed and provided with adequate necessities. However, we do say that overpopulation is not usually the main cause of resource shortfall. We note that the hunger problems occur because of unbalanced economic conditions (in both Marxist and non-Marxist nations), political strife (especially war), locally unanticipated weather shifts, and lack of education and adequate communications. The Malthusian concept would become meaningless if the concepts of the High Frontier were actively pursued [6], but we agree with Kah, et al. [7], that even the colonization of space is not necessary to balance the resource budget. The balance has been achieved in many fortunate areas, and could be achieved everywhere, by the proper attention to advanced technology, especially that which is space-driven.

The Gompertz Curve, shown in Figure 1, is applicable for growth of populations, resource development, technological advance, and many other parameters. For population and technological advance, we are certainly on the cubic increase portion. As Herman Kahn said, forecasting is a matter of predicting where the curve will inflect [8, p. 56]. The doomsayers believe the population will not inflect until disaster by depletion of some resource strikes. Kahn believed that the U.S. bicentennial year, 1976, was at the midpoint of a 400 year cycle, so that the next 200 years would be devoted to assuring a comfortable life of plenty for all the world.

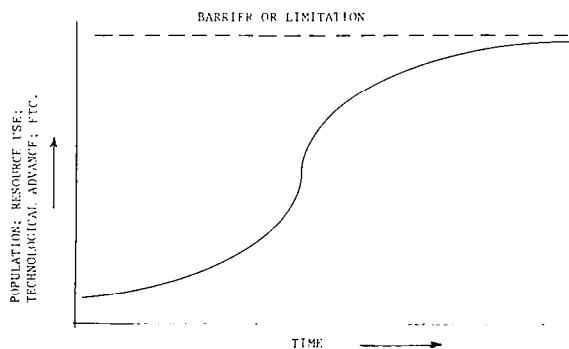


Figure 1. The Gompertz Curve.

Kahn's optimism was confirmed by Julian Simon in his book, The Ultimate Resource. The ultimate resource is the human mind, utilizing the technological ingenuity of mankind [9]. Simon, an economist, bases some of his optimism on commodity market trends. Simon and Kahn have collaborated on a rebutal of Global 2000 called Global 2000 Revised [10].

The modern rebuttal to the Malthusism prophesy is the potential for agricultural technology for greater yields, that is, for growing more food on each acre of land under cultivation. The green revolution did not solve the problem of world food supply; rather it demonstrated an approach to a solution, a method. That method can only be successful only if it is continuously applied to crop improvement. The technological dependence of the agribusiness industry increases with increased demands for food and fibre.

Not only is the agribusiness industry dependent on advances in biotechnology, it is double dependent on advances in space technology.

Space technology must provide the agribusiness industry with the space laboratories in which to develop new crop strains new hybrids; improved information systems for world-wide management of agricultural production and distribution, and crop forecasting.

### III. DEPENDENCE ON TECHNOLOGICAL ADVANCE

The advance of agriculture has come from several technological advances. Increasing mechanization – improvements in the steel plow, the McCormick reaper (1834), and other later machines, steam, gasoline, diesel, and electric engines – made farming more efficient labor-wise, but was not necessary of the increase in food production, given the general labor surplus. There was the factor of release of land needed to feed draft animals, estimated to have been about 80 million acres (32 million hectares) in the U.S. in the peak year of 1919 when there were 21 million horses and mules [11, p. 33]. Production increase came from increases in yield per unit area. Both of these factors were difficult to achieve, once a certain point was reached, but both have proved to be positively affected by technology. We examine both.

Historically, as long as humanity had not yet expanded agriculture onto all arable and grazing land; i.e., all land with sufficient or suitable fertility, water, topography, texture, and climate; increased production was achieved by increasing farm area. In most regions of the world, this limit has been reached, although new plant varieties may permit further expansion onto marginal lands. Aridity is the most widespread limitation on crop production. Irrigation has been used to counter this, and can be expected to continue, especially as new tools assist in construction, new materials improve irrigation equipment (plastic pipe, etc.), and new inventions improve efficiency (center-pivot spray irrigation, trickle feeders). The major limit is the availability of fresh water. A technological advance in sea water desalinization or in transport of sea ice could be a future factor. Areas too cold may occasionally yield to new varieties, as in the examples of grain crops in Canada's Peace River Valley, and the USSR's virgin lands experiments. Wet tropics may accommodate more crops, if certain crops, such as rice, are encouraged; the main barriers are economic and political factors, plus the need to communicate with local and owners and farmers. Remote sensing and a comprehensive data network could go far in optimizing the use of arable and grazing land relative to shipments to areas of demand; i.e., a better balance of supply and demand.

Increase in yield per unit area can result from several technological advances. Supplemental irrigation is currently becoming more prevalent in the eastern U.S. as a yield-increasing technique. Natural and manufactured fertilizers improve yields for crops on lands with adequate water. Chemical and mechanical controls for insects, diseases, and weeds can increase yield, and

for this reason over 10,000 aircraft are used in the U.S. for "ag-air" applications of insecticides, herbicides, fertilizers, seed, and other materials. This billion dollar agribusiness has at least one computerized information service (operated by Econ, Inc., Princeton, NJ\*).

The most publicized yield-increasing technology is that of the "Green Revolution," for which Norman Borlaug, a plant pathologist, won the Nobel Prize for his work in developing high-yield wheat. To date, this has been primarily a result of careful breeding of hybrid varieties of certain important crops and livestock. Lurking on the technological horizon are the potentials of the new biotechnology and gene splicing. The latter technology is also potentially dangerous; a better task for an isolated and quarantined space laboratory cannot be imagined. The potential benefits of plant genetic engineering are worth some risk; think of the possibility of having non-legumes capable of fixing atmospheric nitrogen, even in hostile environments, for example. The new biotechnology has been called the Second Green Revolution, but it also involves livestock animals.

#### IV. SPACE RELATED AGRICULTURAL RESEARCH

##### A. Remote Sensing

The recent development in computer and space technologies and the subsequent marriage of the two gave birth to a new technology – remote sensing.

The recent development of satellites carrying earth-observational sensor systems has made available enormous quantities of photographic and other forms of data about the surface of the Earth, data which have a great potential for helping to solve many human problems: for relieving critical food shortages; for monitoring and controlling environmental pollution; for augmenting shrinking supplies of natural resources; and for planning the orderly growth of cities. In view of these needs, these satellite data are of great human value, provided they can be reduced to useful information both quickly and economically. Modern, high-speed digital computers are well suited to this data-reduction task, and the synthesis of computer technology with the new observations systems has already revolutionized our ability to obtain accurate and current information about the world we live in.

##### B. Computers, Networks, Software, Math Models

It would be unthinkable today to ignore the impact of computer technology on farm management practices. More than 65,000 farmers in this country are already using computers in every facet of farm management and production.

A recent article in a business newspaper [12] stated that 5% of all U.S. farmers now own computers, but this will rise to 45% by 1986. In a report released in March 1983, one market research firm predicted sales of 94,000 microcomputers to farmers by 1987, a value of \$428 million (including software). Any current issue of a farm magazine will contain several advertisements for computers and farm-oriented software. There is a computer magazine for farmers: AgriComp. Perhaps of even greater importance are the several database networks which can feed vital information into the farm computers or even dumb terminals. These include "Agritext," a service of Harris Electronic News in Hutchinson, Kansas; "Agnnet," run by the University of Nebraska; and "AgriStar," offered by AgriData Resources, Inc., of Milwaukee, Wisconsin, and actively marketed by Tandy Corporation's 5,000 Radio Shack stores, dealers, and computer

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\*Mention of commercial business and trademarks is not intended to be an endorsement by the authors or their organizations.

centers. Agnet offers about 200 programs and information services such as crop reports and market prices. Agritext includes 24 hour-per-day agricultural news and other information, such as weather, commodity prices, and market trends. AgriStar is a full two-way communications system, with a comprehensive information service (worldwide agriculture-related weather, commodity prices, agricultural news), an electronic mails system, a catalog "yellow pages" and ordering system, in-depth crop and livestock analysis reports (including specific marketing recommendations), chart displays, several advisory services, an online farm management time-sharing software system which permits modeling, analysis, and forecasting, several commercial and noncommercial library services, and an encyclopedia [13].

These agribusiness database and communications networks are recent entries into the marketplace. Although the Purdue Larsys system has been online for many years, it has been intended for other research stations, not individual farms. AgriStar began service in 1982, but many of its features did not go online until mid-1983. Since this essential market tool was not available, agricultural data from land observation satellites could not be marketed to its most important customers. Instead, it trickled down through federal and state agriculture departments and the research-oriented universities. We recognize that all Earth resources satellite data to date has come from experimental, not operational, satellites. In fact, various technical problems have recently served to remind us that no one has yet made a commitment to provide uninterrupted data. This will soon change, as we have heard in earlier papers at this symposium. We predict that the U.S. agribusiness data base networks will become early and large retailers of satellite data. We also are confident that the global agricultural systems will not be far behind, especially in view of the expected further expansion of communications innovations, such as Intelsat's "Vista," announced in December. We note the beginnings, in 1982 of an international "World Center for Computers and Human Resources" in Paris [14].

### C. Global and Local Communication Improvements

Earlier in this symposium, we had a session on communications from the viewpoint of space commercialization. Now we wish to direct your attention to some of the effects this will have on agriculture and rural development.

We have mentioned the agribusiness data base and communications networks with respect to the inputs, outputs, and output devices (computers and dumb terminals). However, we have not yet discussed the essential linkage, because the U.S. and other developed nations have rather adequate telephone systems. The usual mode is to call a local or toll-free number (or have the computer do it) and use a direct or acoustically-coupled modem for digital data transfer (simplex or duplex). The legal and technical questions about misusing lines leased for voice communication seems to be on the back burner, at least for "personal" computer usage. It is recognized that the frequency response of the ordinary telephone circuit produces some limitations. Professional computer linkages usually consist of higher quality, higher lease cost, lines and microwave relays. A whole new industry, exemplified by Satellite Business Systems, Corp., McLean, VA (SBS), has begun to attack this problem. Their system, which includes direct transmission/reception via small-dish earth stations, is satellite-dependent. Another technological approach being implemented in several cities and along the U.S. East Coast is the optical fiber method. Recognition of the future need for improved linkage has led to certain steps toward the Integrated Services Digital Network (ISDN) by AT&T and GTE in the U.S., British Telecon, Nippon Telegraph and Telephone Public Corp., Thomson-CSF (France) and others, including Germany and Israel [15].

This still leaves a problem for remote rural areas, where an individual farmer or even farm village cannot afford the SBS-type linkage. There are several high-technology solutions suggested for the near future. One is the previously-mentioned good will gesture of Intelsat with their offering of low-cost Vista service to small isolated places by means of satellites and small earth stations. Another is the short-range radio linkage method. Two companies either already offer or propose to offer equipment for this: General Electric's "Personal Radio Communications System" (PRCS), which is intended for voice communications over a 3 to 5 mile range (more with extra repeaters); and Motorola's PCX (Trade Mark) portable digital two-way keyboard/display radio system. A satellite-based two-way digital communications/location/database system has been proposed by Gerard K. O'Neill [16]. It is called the Geostar Satellite System, and includes a pocket-sized keyboard/display, 3 satellites, and a computer center/earth station at Princeton, NJ. Finally, we are beginning to see the new cellular mobile telephone systems in Chicago, and will soon see them in other urban areas. Technologically, it should be possible to place the cellular transceivers in remote rural areas. Perhaps a combination of several of these technologies will prove to be the next step in agribusiness communications.

There have been a number of experimental demonstrations of one-way educational communications to remote areas. These include the ATS-6 television transmissions to remote villages in India. Both Canada and the USSR have operational satellite television transmissions to remote regions in their own nations. Both of these feature a large percentage of instructional material, such as news of agricultural situations and advancements.

Just as the "POT" (plain old telephone) can often substitute for more exotic communication devices, the mail and commercial delivery services can sometimes deliver documents adequately. This was, in fact, necessary for use of Control Data Corporation's (CDC) development-related data base system, DEVELOP. Originally in 1978, DEVELOP was intended to be a two-way online system, utilizing existing telephone linkages. However, poor quality connections, operator intervention, and electrical problems in developing nations forced CDC to operate it, in part, as a mail-in/mail-out search and information service [17].

#### D. Energy Research Related to Agriculture

American (U.S. and Canada) agricultural production is the highest in the world. It is generally acknowledged that this stems, in part, from the American farming practice of energy usage. For that reason, the high rise of fuel costs beginning in 1973 had a marked effect on farm profits and prices; and there was fear that the energy price trends would lead to lower American agricultural production and an eventual disaster in world food supply.

Fortunately, the multipronged approaches to the energy problem have paid off. The conservation approach has not only alleviated shortages, it has also reduced prices. In U.S. agriculture there was a 17 percent drop in energy use per unit of agricultural output from 1974 to 1980. In part, this was due to a shift from gasoline to diesel engines in farm equipment. The U.S. farm usage of the two fuels in 1974 was 3.7 billion gallons of gasoline and 2.6 billion gallons of diesel fuel. In 1980, the respective figures were 2.9 and 3.2, a reversal toward the more-efficient diesel engines. Total farm usage is down. Using figures for the total gallons of gasoline and diesel fuels, 1978 farm consumption was 6.8 billion, 1982 was 5.4 billion, and 1983 was estimated to be around 4.6 to 4.9 billion. Both fuels have also declined in dollar cost, although it must be admitted that electricity, LP gas, and natural gas prices were still climbing, in part due to deregulation [18].

The success of the energy conservation approach in the U.S. does not solve the long range agricultural energy problem, especially in energy-poor (non-OPEC) developing nations. Other prongs point toward cheaper and more abundant energy sources and alternate energy conversion and transmission techniques. First, the fossil fuels themselves may not be in short supply as the doomsayers predicted, given the market price adjustment which encouraged new exploration and new extraction methods. As we have heard earlier today from the Geosat Committee, orbital remote sensing makes important contributions to exploration. The space program has spurred development of solar-electric conversion and fuel cell technology. Ultimately, solar power is always waiting in the wings to save us if all other energy sources become too depleted. Combined with the "hydrogen economy," it or nuclear power could provide inexhaustible energy, just as it already does in the form of fossil fuels, photosynthesis of plants, and production of methyl alcohol.

Nuclear power research continues to progress, in spite of mostly-unjustified sensational no-sayers. Fusion research looks particularly promising for the next decade. Nuclear power can be delivered as electricity, or, if portable energy is required for vehicles, tractors, etc., hydrogen could be efficient transfer medium. Do we need to remind this audience where the techniques for use of hydrogen are being applied now?

Coal is quite abundant world-wide, and especially in the U.S. Unlike nuclear power, however, it is quite hazardous to health as presently used. Emphasis in research has concentrated on efficiency, pollution control, and exploitation with minimum ground disturbance. New techniques related to coal are magnetohydrodynamics and underground gassification.

We agree with Simon [9], Stine [8], and Kahn [19] that abundant cheap energy is a key factor in future human well-being, and that it is well justified to expect it. We expect space research to drive the technology for abundant energy commercialization.

## V. THE HOPEFUL FUTURE

At an October 1983 ceremony marking the 25th anniversary of NASA, President Reagan spoke of a "high road" for space policy. In the January 1984 State of the Union address, he added a detail, the space station. These policy decisions reflect an optimism and a reliance on the ability of technological innovation to overcome resource problems.

We have outlined an optimistic approach to the application of space technology for agricultural resources.

During an international symposium in 1955, Anthropologist Sol Tax read a poem composed by Kenneth Boulding [20]. It summarizes our feelings and is quoted here:

## A CONSERVATIONIST'S LAMENT

The world is finite, resources are scarce,  
Things are bad and will be worse.  
Coal is burned and gas exploded,  
Forests cut and soils eroded.  
Wells are dry and air's polluted,  
Dust is blowing, trees uprooted.  
Oil is going, ores depleted,  
Drains receive what is excreted.  
Land is sinking, seas are rising,  
Man is far too enterprising.  
Fire will rage with Man to fan it,  
Soon we'll have a plundered planet.  
People breed like fertile rabbits,  
People have disgusting habits.

Morale:

The evolutionary plan  
Went astray by evolving Man.

## THE TECHNOLOGIST'S REPLY

Man's potential is quite terrific,  
You can't go back to the Neolithic.  
The cream is there for us to skim it,  
Knowledge is power, and the sky's the limit.  
Every mouth has hands to feed it,  
Food is found when people need it.  
All we need is found in granite  
Once we have the men to plan it.  
Yeast and algae give us meat,  
Soil is almost obsolete.  
Men can grow to pastures greener  
Till all the earth is Pasadena.

Morale:

Man's a nuisance, Man's a crackpot,  
But only Man can hit the jackpot.

## REFERENCES

1. Paddock, William, and Paul Paddock. Famine 1975! (out of print)
2. The White House: The World Food Problem. A Report of the President's Science Advisory Committee, Washington: U.S. Gov't Printing Office, May 1967.
3. Meadows, D. H., D. L. Meadows, Jorgen Randers, and William W. Behrens, III: The Limits to Growth. New York: Universe Books, 1972.
4. Forrester, Jay W.: World Dynamics. Cambridge, MA: Wright-Allen Press, 1971.
5. Barney, Gerald O. (Ed.): Global Two Thousand Report to the President of the U.S. New York: Pergamon Press, 3 Vols., 1984.
6. O'Neill, Gerard K.: The High Frontier; Human Colonies in Space. New York: William Morrow and Co., Inc., 1977.
7. Kahn, Herman, William Brown, and Leon Martel: The Next 200 Years. New York: Quill (William Morrow and Co.), 1976.
8. Stine, G. Harry: The Hopeful Future. New York: MacMillan Publishing Co., 1983.
9. Simon, Julian L.: The Ultimate Resource. Princeton, NJ: Princeton University Press, 1981.
10. Holden, Constance: "Simon and Kahn Versus Global 2000," Science, Vol. 221, pp. 341-343, July 22, 1983.
11. Anderson, James R.: A Geography of Agriculture. Dubuque, Iowa: Wm. C. Brown Co., 1970.
12. Cox, Meg: "Farmers Growing Demand for Computers Draws Many High-Tech Firms Into Market," The Wall Street Journal, Dec. 22, 1983, p. 27.
13. AgriStar Review. Biweekly newsletter. AgriDate Resources, Inc., 205 W. Highland Ave., Milwaukee, WI 53203.
14. Shaffer, Richard A.: "Computer Center Seeks to Aid Poor, Jobless and Third World," The Wall Street Journal, July 15, 1983, p. 29.
15. Shaffer, Richard A.: "Future Phone," The Wall Street Journal, Dec. 23, 1983, pp. 1&6.
16. O'Neill, Gerard K.: "Satellite Air Traffic Control," Astronautics and Aeronautics, Vol. 19, No. 3, March 1981, pp. 27-31.
17. Clifford, Ellen: "Data Banks for Development Mean Business," Horizons, Nov. 1983, pp. 8-9.
18. Duncan, John: "U.S. Farmers Reap Energy Savings," Farmline, July 1983, pp. 12-13.
19. Kahn, Herman: The Coming Boom. New York: Simon and Schuster, 1982.
20. Thomas, William L., Jr. (Ed.): Man's Role in Changing the Face of the Earth. Chicago: Univ. of Chicago Press, 1956.



## SMALL PAYLOAD FLIGHT SYSTEM (SPFS)

by

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Developed by Teledyne Brown Engineering, the Small Payload Flight System provides a simple and cost-effective approach to carrying small size experiments on the Space Shuttle. The system uses a bridge-like structure which spans the Orbiter Cargo Bay but is only 3 feet in length. The structure can carry up to 4300 lb of payload weight and can be positioned at any location along the length of the cargo bay.

In addition to the structural support, the SPFS provides avionics services to experiments. These include electrical power distribution and control, command and telemetry for control of the experiments and subsystem health monitoring, and software computations. The avionics system includes a flight qualified electrical power branching distributor, and a system control unit based on the Intel 8086 microprocessor. Data can be recorded on magnetic tape or transmitted to the ground. Finally, a Freon pump and cold plate system provides environmental control for both the avionics hardware and the experiments as necessary.

The bridge structure was used for the first time to carry several material experiments on Flight 7 of the Space Shuttle. Designated OSTA-2, this mission demonstrated the application of the system and was a complete success.

*This paper presents the Teledyne Brown Engineering concept for a commercial carrier system envisaged for the future. Teledyne Brown Engineering is presently engaged in discussions with the National Aeronautics and Space Administration with the intent of negotiating an agreement with the Agency for the Company to develop, own, and operate this system in the future. The contents of this paper are therefore presented for information only and do not constitute any commitment by Teledyne Brown Engineering to develop the system.*

## SMALL PAYLOAD FLIGHT SYSTEM (SPFS)

### 1.0 BACKGROUND

During the past several years, as part of the payload integration task for the Marshall Space Flight Center (MSFC), Teledyne Brown Engineering has developed the Mission-Peculiar Equipment Support Structure (MPESS). The MPESS is a bridge-like structure, only 3 feet in length, and designed to occupy only a small section of the Orbiter cargo bay. The first payload to use the MPESS was the MSFC-managed OSTA-2 materials science payload which was flown in June 1983 as part of the STS-7 cargo.

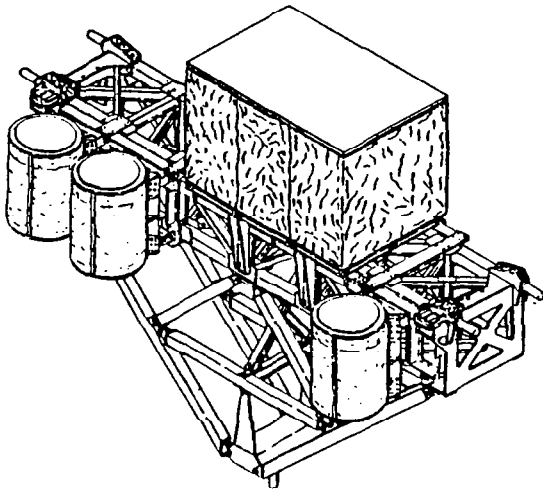


FIGURE 1-1. MSFC OSTA-2 PAYLOAD

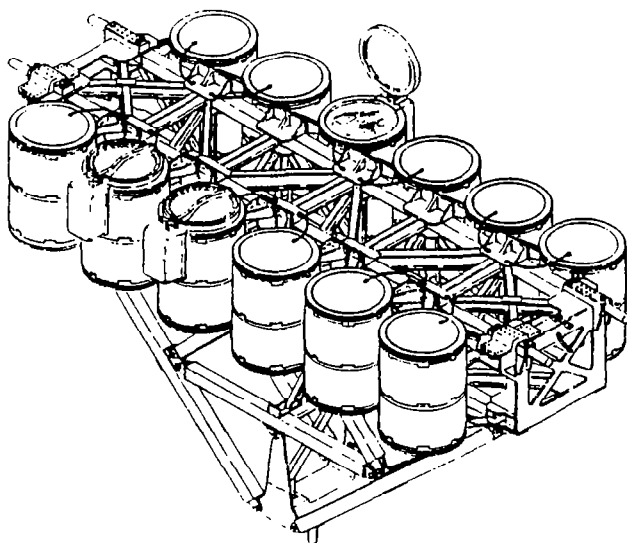
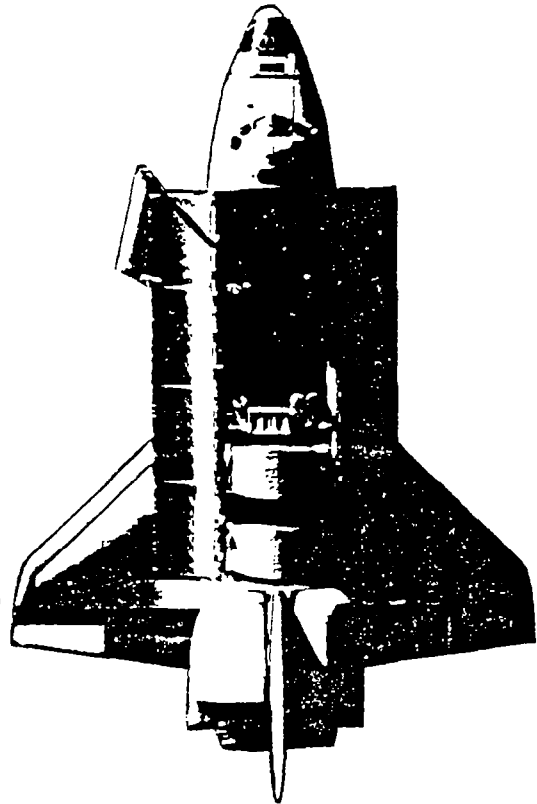


FIGURE 1-2. GAS BRIDGE PAYLOAD

The structure will be used for other MSFC applications and has more recently been adapted for two Goddard Space Flight Center programs, the GAS Bridge and SPARTAN.

In the SPARTAN application, the MPRESS will carry a deployable free-flying satellite and in the GAS Bridge program up to 12 cannisters will be mounted on the sides of the MPRESS. In some of the MPRESS applications, support subsystems to provide power, cooling, and data handling have been mounted on the structure. For example, the OAST-1 payload, shown below, is an MSFC-managed program, and in this application, power and data handling are provided by the avionics subsystem boxes shown.

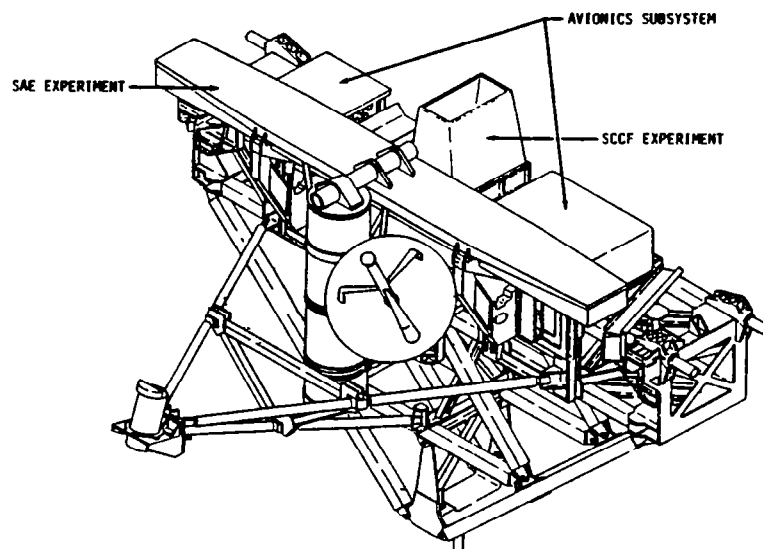


FIGURE 1-3. MSFC OAST-1 PAYLOAD

Teledyne Brown Engineering is now completing the development of the Material Sciences Laboratory (MSL) for MSFC. The MSL is based on the MPRESS but will include subsystems for power distribution, command and data handling, high density tape recording of data, environmental control, and low-gravity acceleration measurement. The MSL is first scheduled to carry the MSL-2 payload in December 1984.

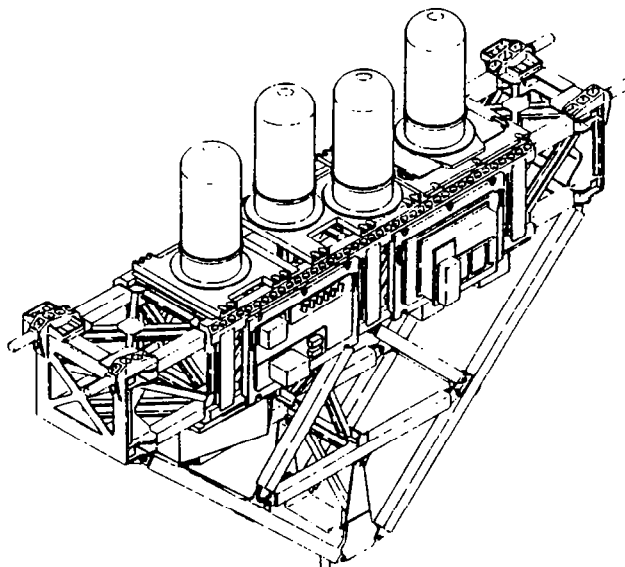


FIGURE 1-4. MSFC MSL-2 PAYLOAD

The evolution of the MPRESS-based carrier fleet has led Teledyne Brown Engineering to study the potential need for a commercial carrier system which would be owned and operated by the Company and designed to provide low cost, quick turnaround, and frequent flight opportunities to the user. The result of this research is the Small Payload Flight System (SPFS) representing a step forward in the MPRESS carrier evolution and designed toward the ultimate goal of commercialization in space.

## 2.0 SPFS SYSTEM DESCRIPTION

SPFS is a carrier system to which experiment equipment can be mounted in the Orbiter cargo bay. It is short in length, can be located at a wide range of stations, and offers the standard one-quarter section allocation of STS resources. In addition, the system is designed to meet launch dates as close as 6 months from manifesting.

Standard experiment-to-carrier interfaces and a fixed configuration for subsystem equipment are fundamental to the SPFS concept. These features minimize the cost and shorten the schedule for payload integration, and also reduce the time from manifesting to return of experiment data and hardware. The SPFS carrier system with candidate experiment systems mounted and integrated is shown in Figure 2-1.

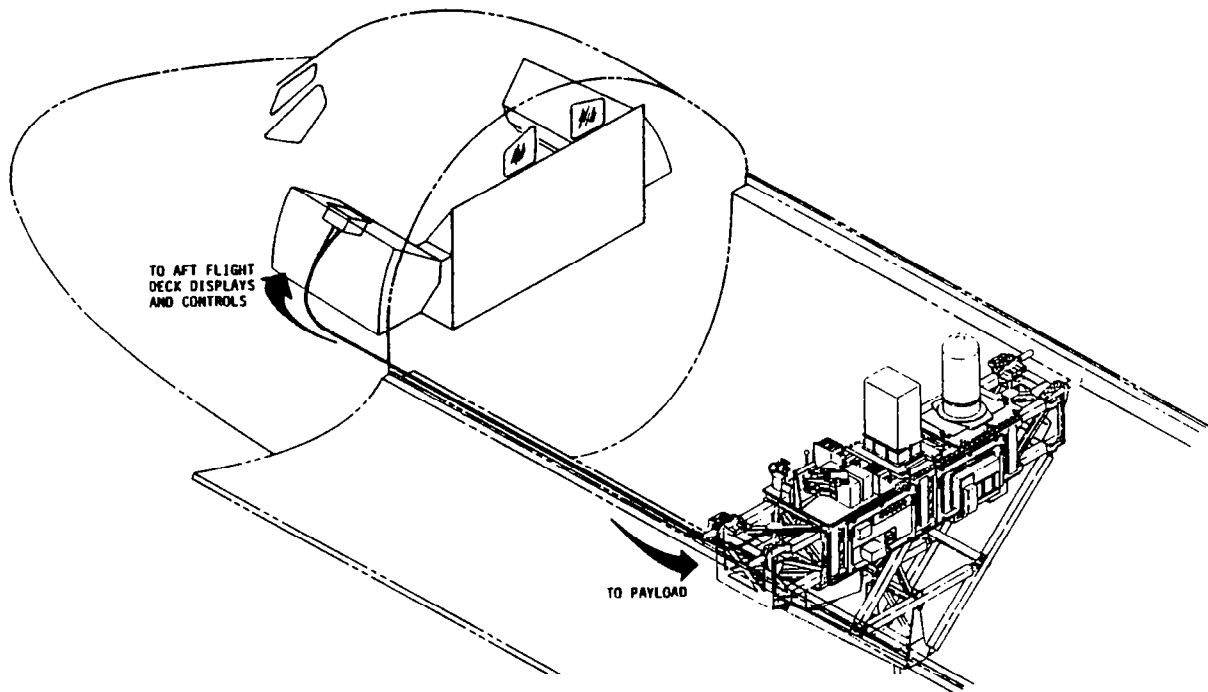


FIGURE 2-1. SPFS CARRIER SYSTEM WITH EXPERIMENTS

The SPFS with subsystems will support up to three experiments on each mission. Subsystem provisions include a standard structural mounting system, electrical power switching and distribution, command and data management, and environmental control. Table 2-1 shows the subsystem provisions and the nominal envelope of accommodations available to each experiment.

TABLE 2-1. SPFS SUBSYSTEM PROVISIONS

<u>SUBSYSTEM</u>	<u>TOTAL AVAILABLE (NET)</u>	<u>NOMINAL 1/3 ALLOCATION (INDIVIDUAL USER)</u>
<b>Structural/Mechanical</b>		
Mass Capability (lb)	3,000	1,000
Mounting Area (ft <sup>2</sup> )	58	20
<b>Electrical Power</b>		
dc Power, Peak (W)	2,427	810*
dc Power, Continuous (W)	1,550	515
Total Energy (kWh)	115	38
<b>Command/Data Management</b>		
Switch/Indicator Pairs	10	3
Health Data Channels	176	58
Exp. Command Channels	128	42
Scientific Data Rate (kbps)**	16	16***
Timing Channels (GMT or MET)	3	1
<b>ECS</b>		
Coldplates	2	1
Coldplate Heat Rejection (kW)	2.1	0.7
Cooling Internal (kW)	2.1	0.7

\*Peak and Continuous Durations Constrained by Energy Limit

\*\*16 kbps for Continuous PDI or ETR Data. Max ETR data rate is 1 Mbps

\*\*\*Indicates Time Shared when Downlink is Used.

The following sections provide a detailed description of each subsystem and its capabilities.

## 2.1 Structural/Mechanical Subsystem

The SPFS carrier provides standard structural mounting for small experiment systems. Experiment hardware may be located either on the top or side surfaces of the SPFS structure. A structural rail and plate system provides a standardized interface approach which reduces new hardware requirements and recurring analysis for reflight of the carrier (Figure 2-2).

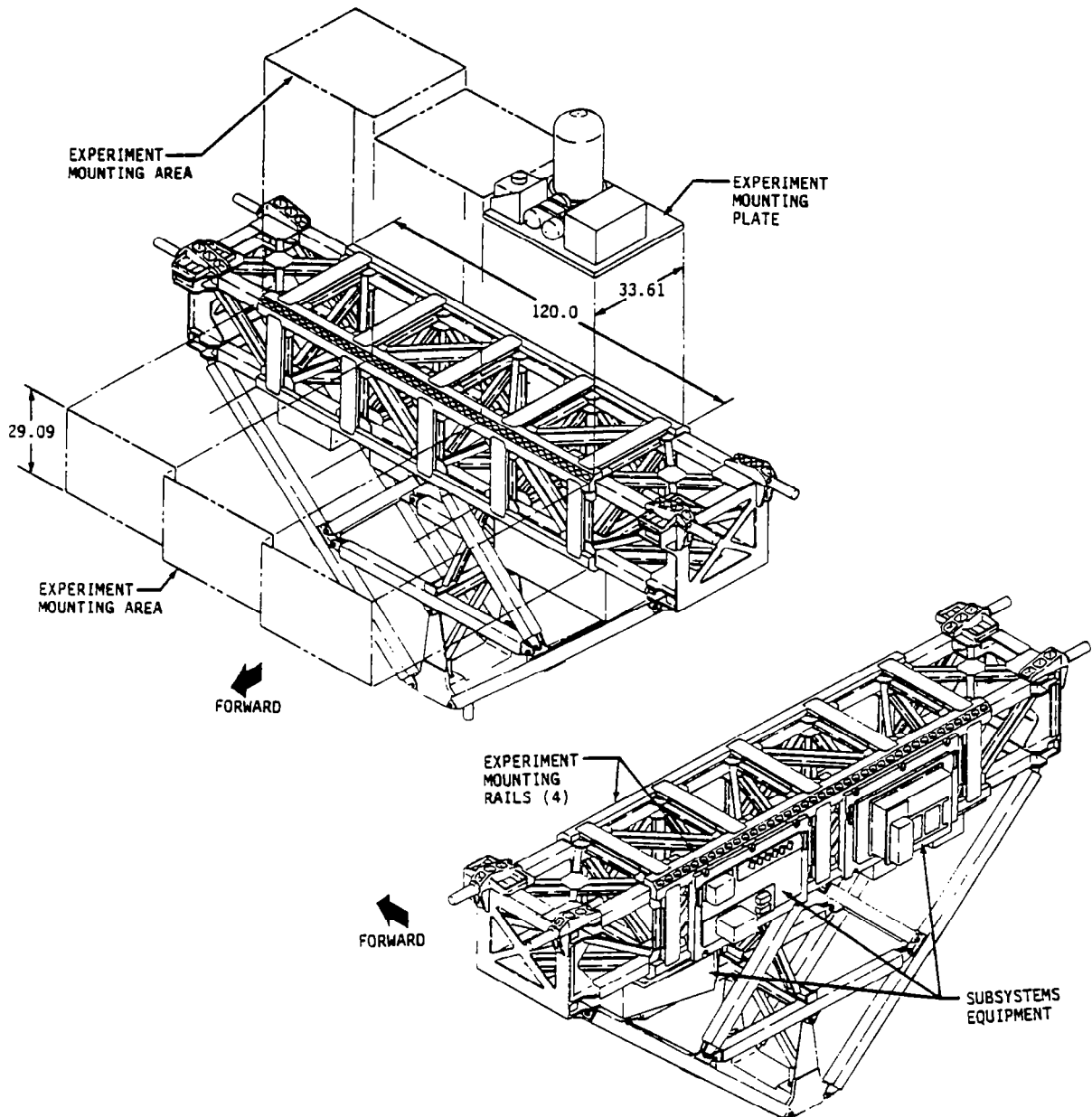


FIGURE 2-2. SPFS STANDARD STRUCTURAL INTERFACE

Each mounting surface has been divided into three sections. The three top sections are nominally 41.5 by 40 in., while the three side sections are nominally 28 by 40 in. For users requiring coldplates, certain areas will contain coldplate surfaces approximately 20 by 35 in., centered within the 28 by 40 in. area.

To interface directly to the SPFS, the experiment developer would provide a mounting plate as part of his experiment assembly. This plate would span the structural rails, Figure 2-3. The mounting plate is not considered an integral part of the structure and, therefore, would not be required to carry any primary structural loads. Where a coldplate is required for heat dissipation, the same attachment concept is utilized.

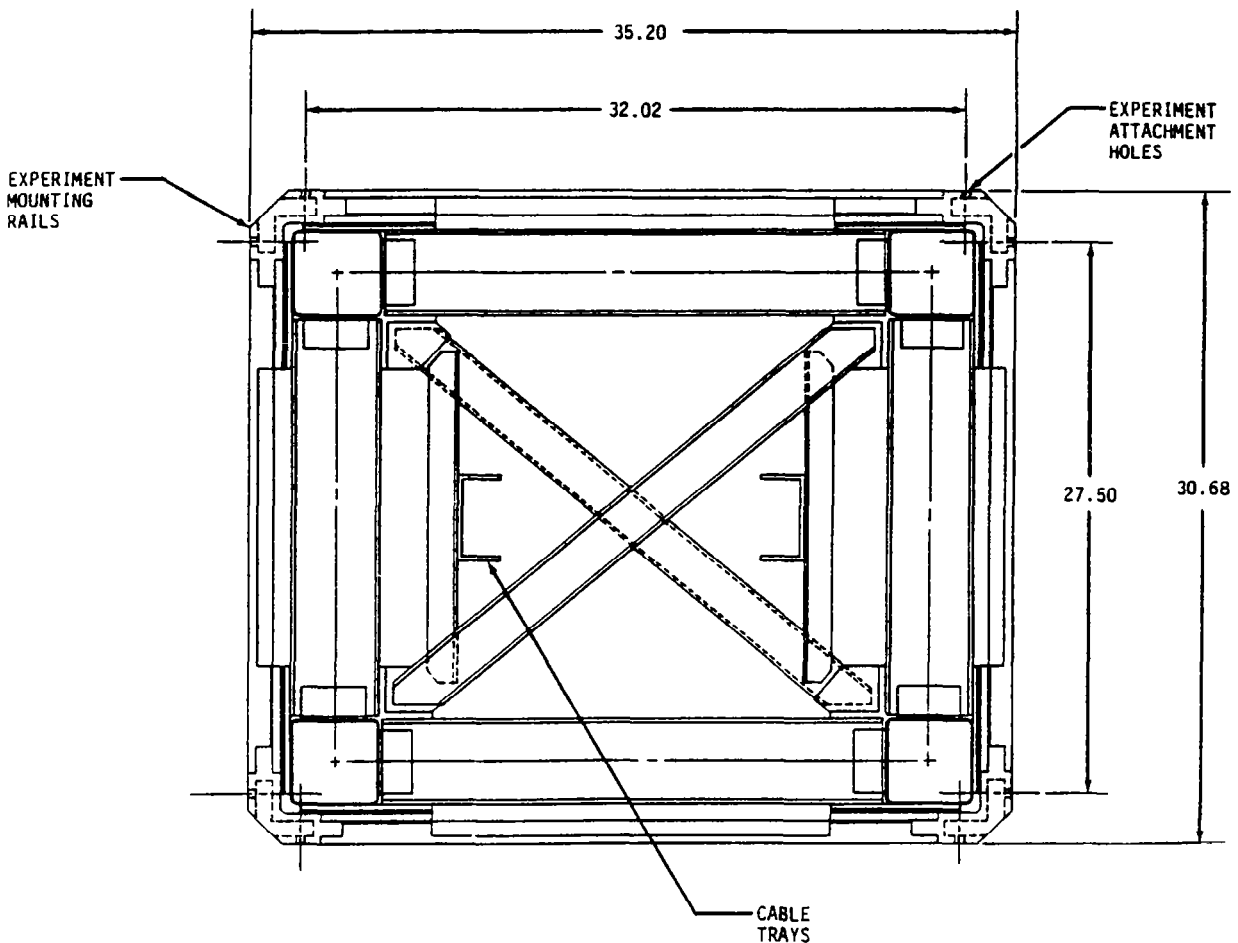


FIGURE 2-3. EXPERIMENT MOUNTING SYSTEM

The SPFS system will accommodate instruments which fit within the mass properties envelope of Figure 2-4 without the need for extensive structural/dynamic modeling. Center of gravity offset is measured from the top of the primary MPSS structure to which coldplates and adapter plates are mounted. Single section instruments with a mass greater than 1000 lb or a severe c.g. offset may be accommodated, but will require a special analysis.

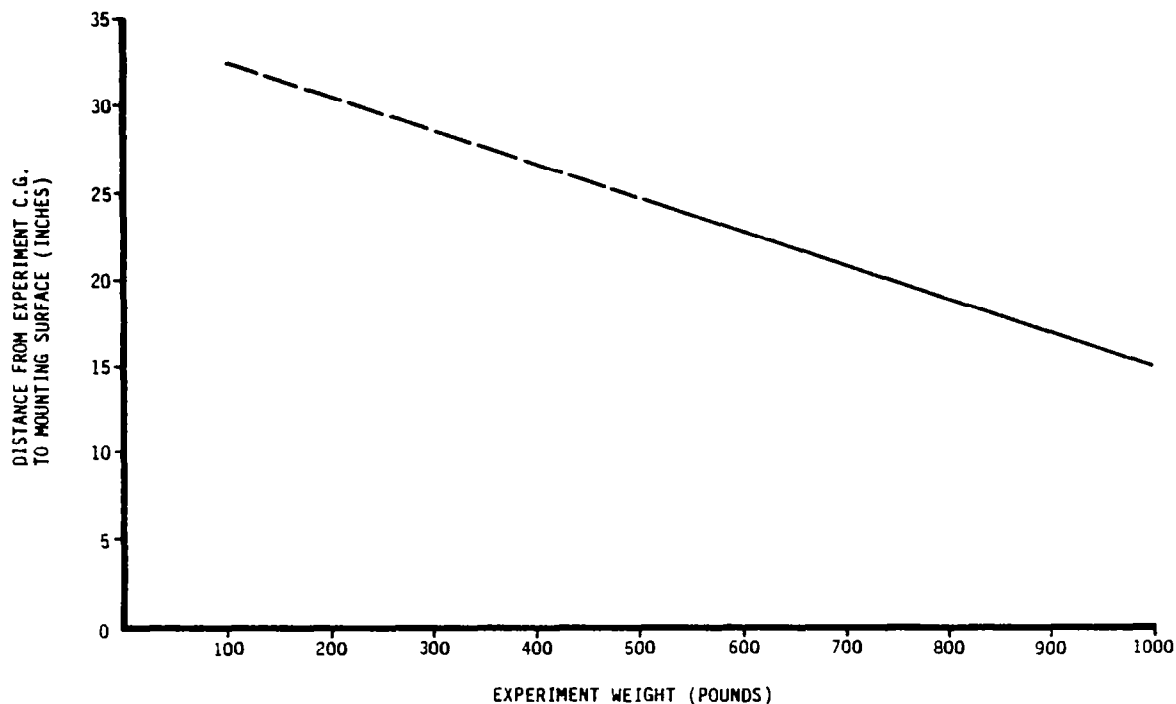


FIGURE 2-4. PAYLOAD MASS CAPABILITY

## 2.2 Environmental Control Subsystem

A Freon coolant loop system (Figure 2-5) circulates coolant between the SPFS subsystem coldplates, the experiment coldplates, experiment heat exchangers and the Orbiter payload heat exchanger. Freon circulation is provided by the SPFS pump. Multilayer insulation, heater elements, and surface coatings will be used, as necessary, for additional thermal control.

The experiment coldplates will be connected in parallel to the SPFS cooling loop. The temperature extremes of the coldplates will be about 2°C to 49°C and the rejection capacity of each coldplate is expected to exceed 2000 W.



Heat exchangers or coldplates which are integral components of an experiment system could be connected into an existing parallel leg at the Experiment Fluid Service Panel by disconnecting one of the SPFS coldplates.

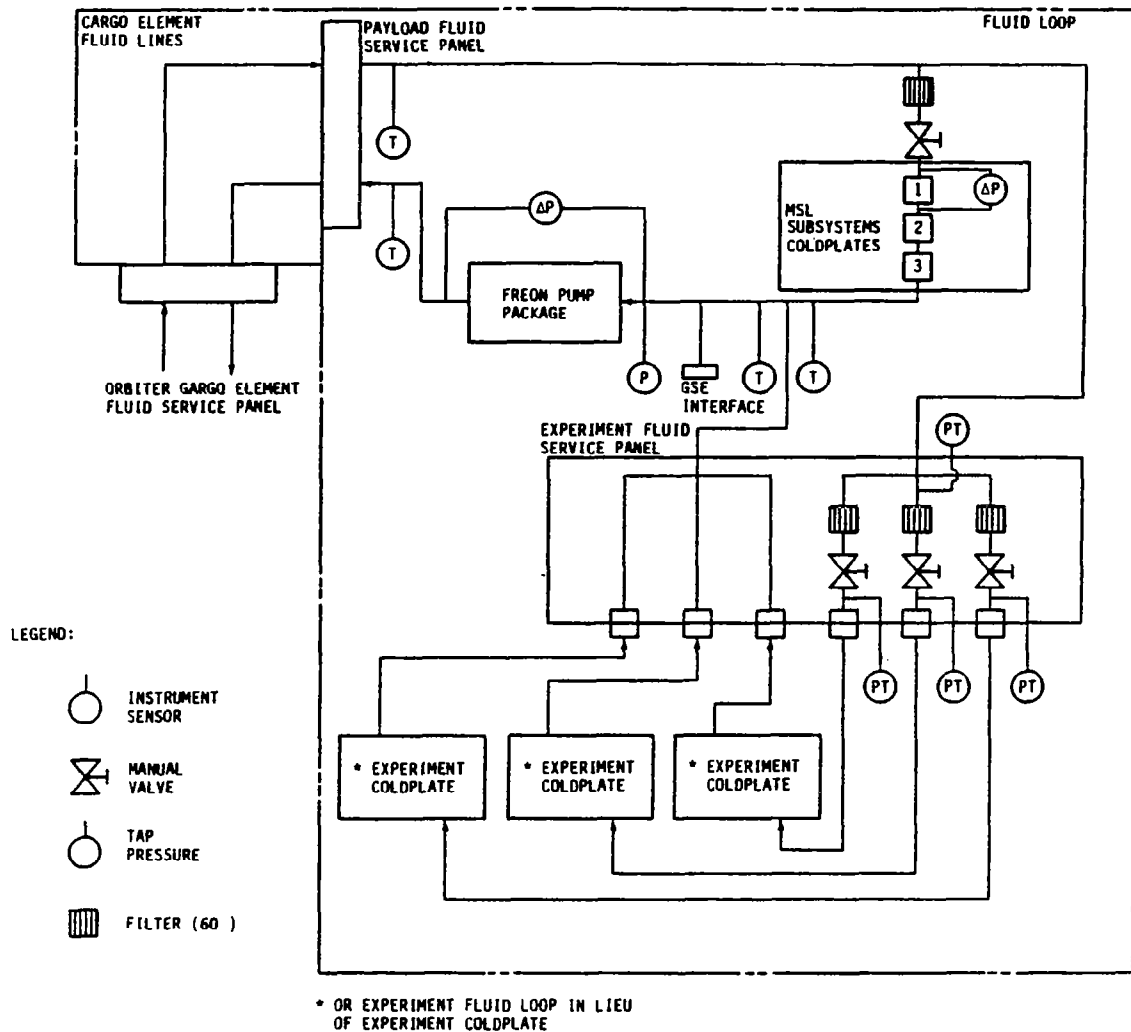


FIGURE 2-5. ACTIVE COOLANT LOOP

### 2.3 Power Control Subsystem

The SPFS concept includes a power distributor to provide 28 Vdc power to the subsystems and experiments. Latching relays in the distributor enable individual circuits to be energized from the AFD by crew commands. A switch on the AFD standard switch panel will activate the Power Distributor main power, while commands which control power circuits to the experiments are entered at the Command Display Management Panel (CDMP).

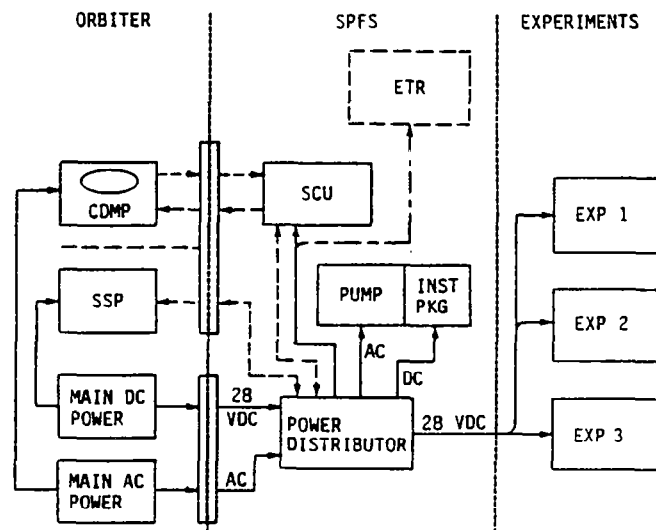
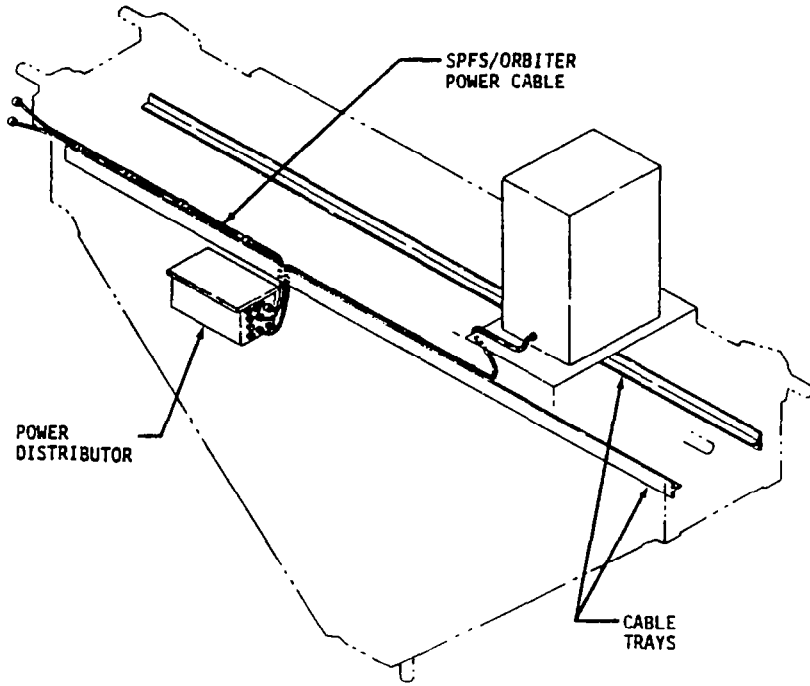


FIGURE 2-6. ELECTRICAL POWER SUBSYSTEM

A total of 222.5 kWh will be available to the SPFS. Based upon a 6-day usage of energy, nominal 28 Vdc, and considering the power for the SPFS subsystems, 115 kWh will be available to the experiments at rates as high as 2427 W (for short duration) or 1550 W continuously.

## 2.4 Command and Data Subsystem

Experiments are expected to range from those that are autonomous to those that will require the full SPFS resources. The following SPFS command and data accommodations are presently planned:

- Aft Flight Deck (AFD) Standard Switch Panel (SSP) operations
- Crew control using the CDMP
  - Crew initiated commands and command sequences
  - Onboard display of health/status data
- Experiment data downlinking at up to 16 kbps
- Experiment PCM data recording at up to 512 kbps
- Experiment timing accurate to  $\pm 10$  msec
- Preflight interface verification at the user facility
- Crew training.

The command and data system to support experiment operations is shown in Figure 2-7. Note that the SPFS does not interface with the Orbiter General Purpose Computer (GPC), thereby avoiding the need for long-lead time GPC software development.

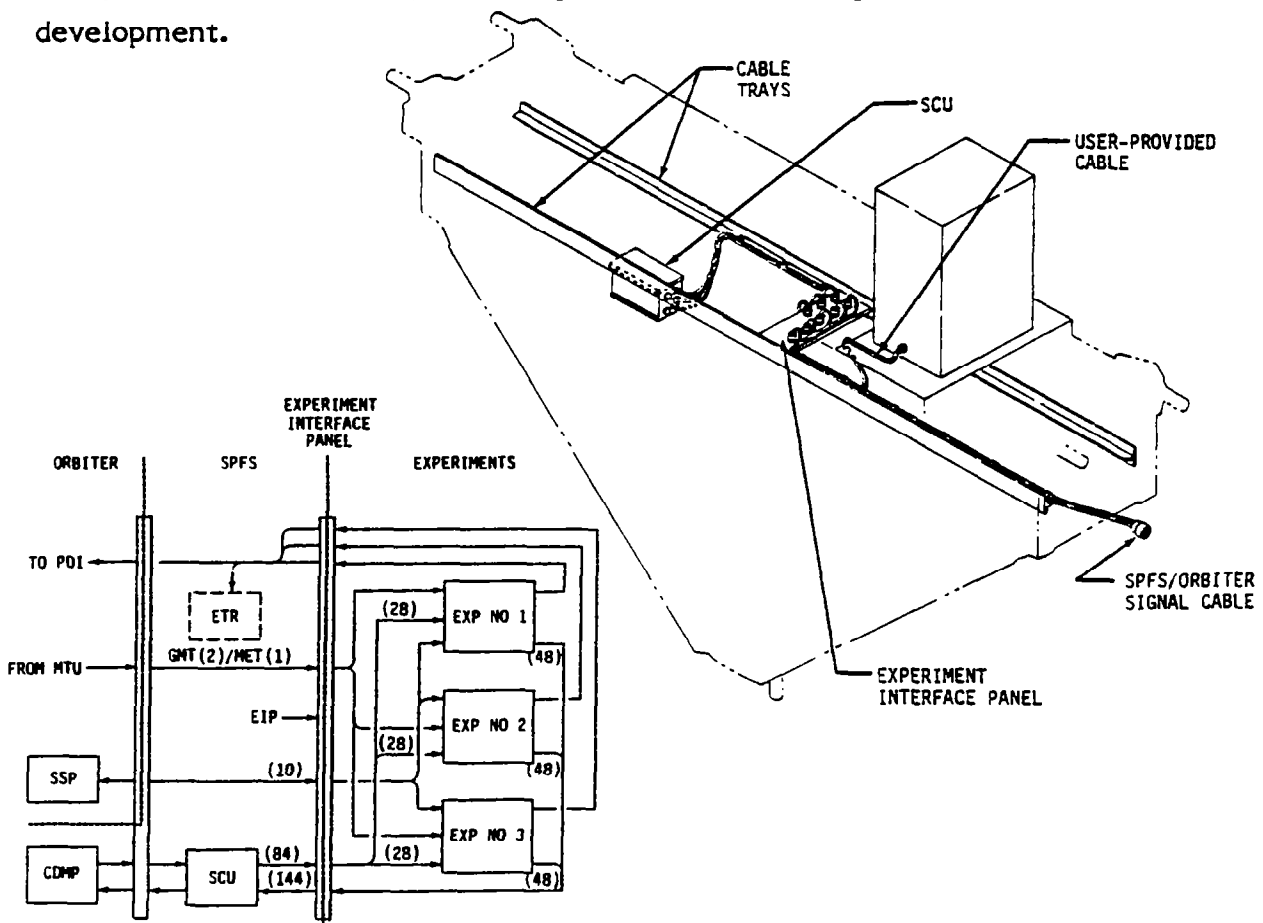


FIGURE 2-7. CDMS CONCEPT

For control purposes, 10 switch/indicator pairs are available on the SSP for sharing among the experiments. Three of these constitute the standard allocation for an individual experiment.

The SPFS Command/Display Management Panel (CDMP) is a computer terminal in the AFD which will interact with the System Control Unit (SCU) 8086 microprocessor-based computer through an RS-422 link. Together they provide a commanding capability as well as a means of monitoring experiment health and status data. A total of 84 commands and 144 measurement type channels are available for experiment sharing. The individual user allocation is 28 commands and 48 measurement channels.

The Experiment Tape Recorder (ETR) is provided for onboard recording of SPFS data. The ETR has a capacity of  $2.5 \times 10^{10}$  bits of data and can accept biphase PCM at rates of up to 512,000 bits per second. Nominally, the ETR will record experiment analog and digital data collected by the SCU at rates of 3,000 to 32,000 bits per second. The system can be reconfigured to accept direct experiment PCM or analog data.

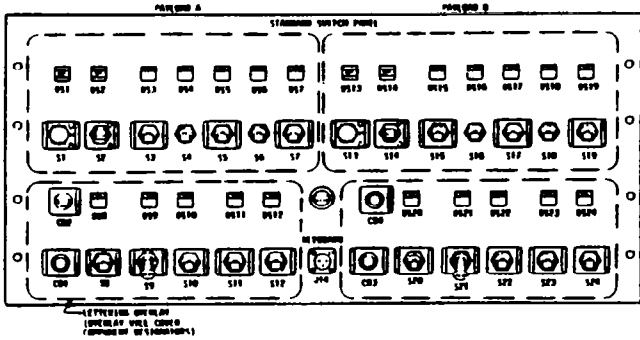
As an option, users can transmit PCM data to the ground through the Orbiter PDI at a rate of up to 16 kbps. User data may be fed to the PDI directly or indirectly through measurements acquired by the SCU. The SCU can simultaneously record data on the ETR while transmitting data to the ground through the PDI.

Time data originates at the Orbiter Master Timing Unit. The user may accept serial time data directly or may have his data time tagged upon collection by the SCU.

#### 2.4.1 Crew Interface

Experiment operation may be autonomous or permit crew interaction from the Aft Flight Deck Standard Switch Panel (SSP) and the SPFS CDMP, Figure 2-8. Through the CDMP the crew may change the operational mode of the experiment system, initiate a special sequence, change data rate, check critical voltages, etc.

The CDMP is a SPFS-dedicated unit containing a plasma screen for data display and a keyboard for commanding. As a standard service, up to 96 measurements will be converted to engineering units and displayed on the CDMP. Also, 96 commands will be available for keyboard commanding to user instruments via the SCU. These measurements and commands will be shared among users.



STANDARD SWITCH PANEL (SSP)

COMMAND/DISPLAY MANAGEMENT PANEL (CDMP)

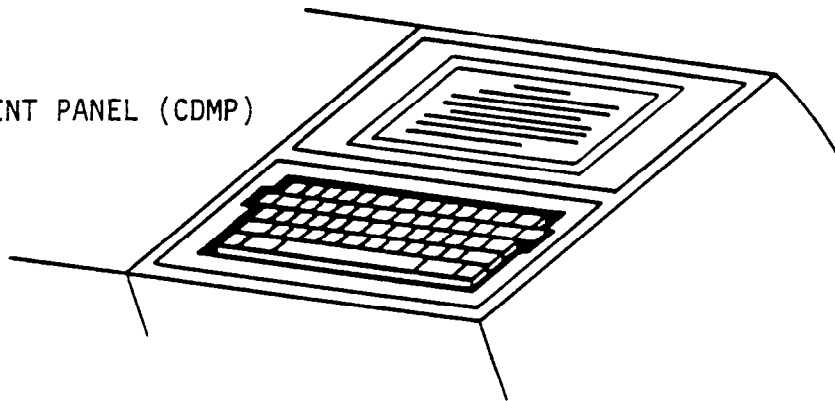


FIGURE 2-8. CREW INTERFACES

### 3.0 SPFS SERVICE TO THE USER

Figure 3-1 illustrates the range of services which Teledyne Brown Engineering expects to provide to the user.

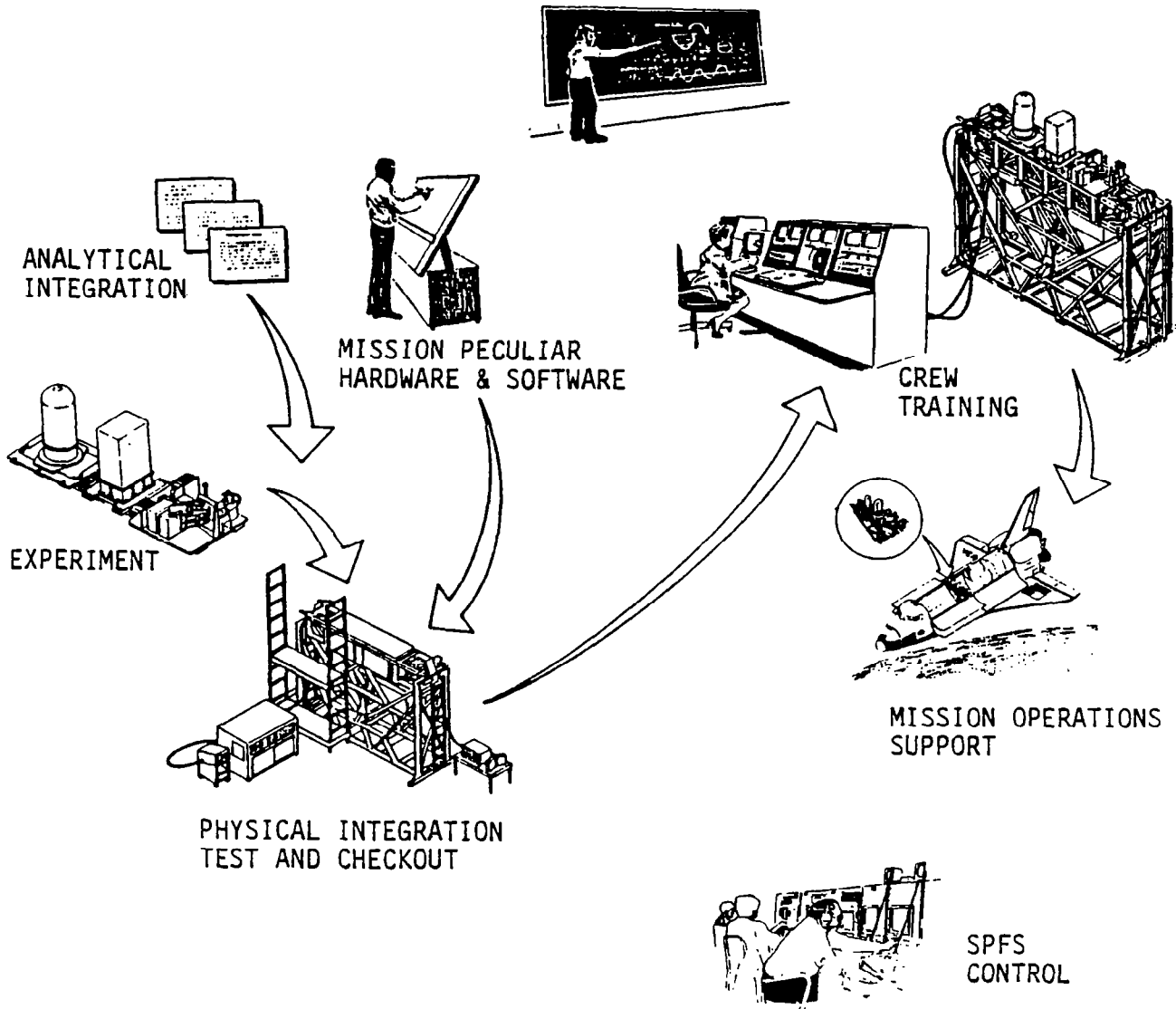


FIGURE 3-1. SPFS USER SERVICES

These services include analytical payload integration and the associated development of mission-peculiar hardware or software if this is required to interface with the experiments. Physical integration test and checkout of each payload will be conducted by Teledyne Brown Engineering; a more detailed integration test and checkout configuration is illustrated in Figure 3-2.

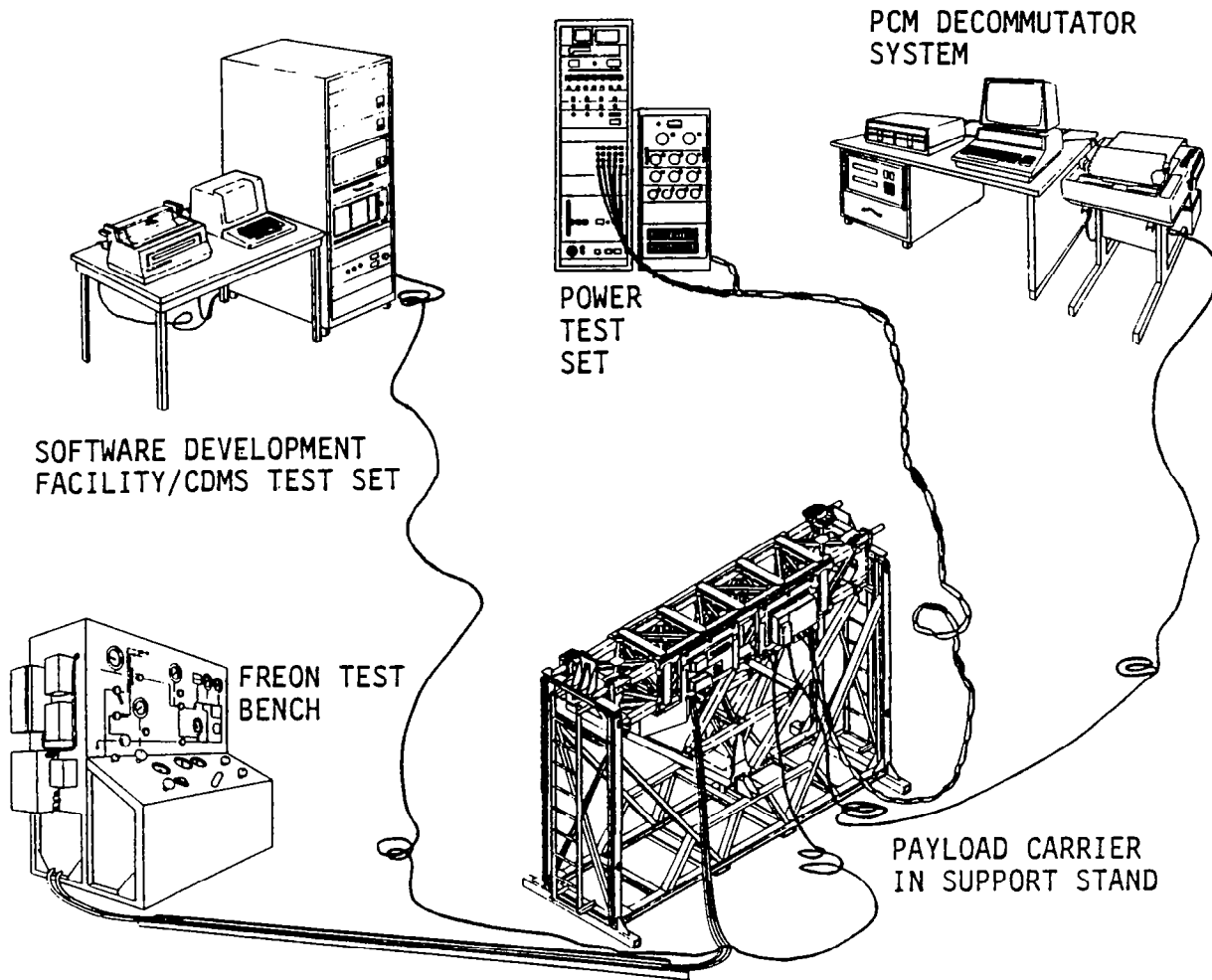


FIGURE 3-2. SPFS INTEGRATION AND TEST CONFIGURATION

Crew training, if necessary, will be conducted using a CDMP simulator which will enable the crew to exercise each SPFS flight configuration and become familiar with the experiment operational requirements. Finally, Teledyne Brown Engineering will provide real-time mission operations support to ensure smooth operation of the SPFS payload in flight.

Figure 3-3 shows the overall plan to complete the SPFS development and prepare the system for flight. Integration of the first payload is expected to require about 10 months, but the ultimate objective will be to reduce this period to 6 months.

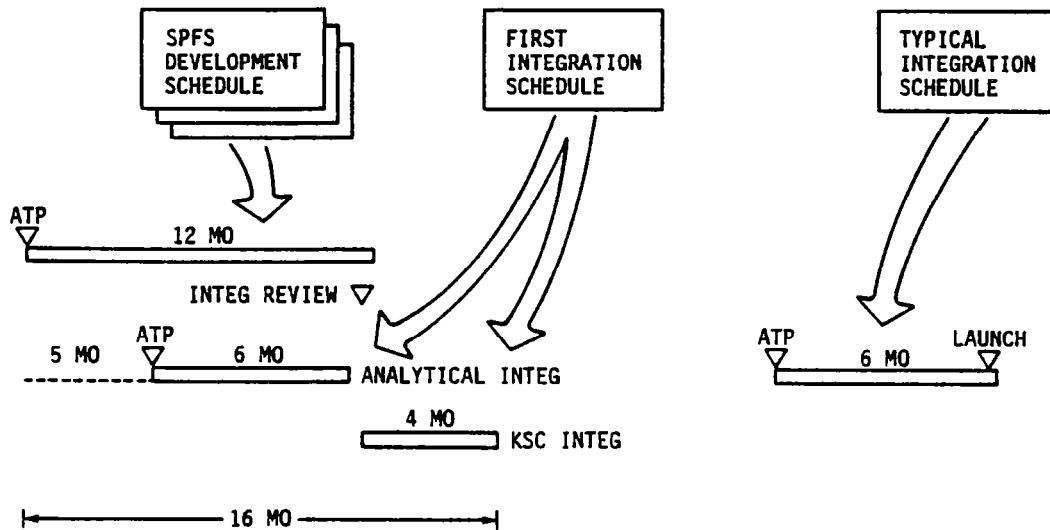


FIGURE 3-3. DEVELOPMENT AND INTEGRATION PLAN OVERVIEW

#### 4.0 SUMMARY

In summary, Teledyne Brown Engineering has developed a concept for a future commercial carrier system. The SPFS is designed for low cost and rapid turnaround. The system provides a structural support using the Mission Peculiar Equipment Support Structure (MPRESS), equipped with a full range of support subsystems including power distributor, command and data control, data recording and environmental control. The system will provide standard services to the user and will, in turn, operate within the STS standard services. This approach will ensure that the integration process is simple and can be provided at low cost to the user.



# MODULAR EXPERIMENTAL PLATFORM FOR SCIENCE AND APPLICATIONS

by

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## ABSTRACT

Boeing has been involved in the production of small, low-cost space vehicles since the mid-60's including 20 booster upper stages, 7 USAF satellites, 2 NASA satellites and the first Swedish satellite to be launched in 1985 on Ariane. Based on this heritage, Boeing has developed a modularized, standardized spacecraft bus, known as MESA, suitable for a variety of science and applications missions.

The basic bus consists of a simple structural arrangement housing attitude control, telemetry/command, electrical power, propulsion and thermal control subsystems. The general arrangement allows extensive subsystem adaptation to mission needs. Kits provide for the addition of tape recorders, increased power levels and propulsion growth. Both 3-axis and spin stabilized flight proven attitude control subsystems are available.

The MESA bus can be launched on Ariane, as a secondary payload for low cost, or on the STS with a PAM-D or other suitable upper stage. Multi-spacecraft launches are possible with either booster. Launch vehicle integration is simple and cost-effective.

Depending on specific mission requirements (which determine equipment selection and delivery), the MESA bus can be generally integrated and delivered in approximately two years after contract award.

The low cost of the MESA bus is achieved by the extensive utilization of existing subsystem design concepts and equipment, efficient program management and test integration techniques, the assignment of a proven, experienced Boeing design team and use of program-dedicated manufacturing, materiel, contracts and finance support experienced in small, low-cost space vehicle programs.

## TEXT

Introduction. In 1964, almost two decades ago, Boeing was awarded the USAF Burner II Thor upper stage contract which eventually led to 12 Burner II launches, 8 Burner IIA launches and the series of spacecraft shown in Figure 1. The early spacecraft designs used the Burner II/IIA as a 3-axis space platform by integrating payloads directly onto the booster upper stage. In the mid-70's, separate satellites were designed and successfully flown. The STP P72-1 spacecraft was the first vehicle that was not a direct derivative of the Burner II/IIA upper stage. Since that time, all of the Boeing small, low cost spacecraft have been independent satellites; the Burner II/IIA stage is no longer in production.

The chart (Figure 1) shows the program costs and the delivery schedules for these Boeing spacecraft. The costs are "then year" dollars so have to be inflated from the 60's to current dollars to make direct comparisons. However, a number of observations are possible:

- .Vehicle costs are very low compared to conventional spacecraft. The methodologies used to achieve these low costs are discussed later in this paper.
- .Delivery schedules are short but with a trend toward lengthening. The primary reason for the schedule stretches were supplier delivery problems due to the great demand for space quality components (IC's especially) and connectors in the 70's time frame.
- .Low cost doesn't mean low reliability. A launch success of 96.4% has been experienced to date. Since the SESP 68-1 failure was due to a booster shroud malfunction, we can claim 100% success for vehicles that achieved orbit.

The Swedish Viking Bus is to be launched on the Ariane booster in 1985 and we are discussing future small low-cost spacecraft programs with a number of domestic and foreign potential customers. We expect to continue this business for a long time including new commercial ventures currently under investigation.

Based on this extensive heritage, Boeing has developed a modularized, standard spacecraft bus, known as MESA, which is suitable for a variety of missions and adaptable to either Ariane or Shuttle launch systems. The remainder of this paper presents this bus concept in some detail and summarizes its applicability to typical science and applications missions.

MESA Bus Design. The general arrangement of the MESA platform is depicted in Figure 2. The central core section is the primary structural body and contains the majority of the housekeeping equipment and spacecraft subsystems. The octagonal outer structure can be mission unique and provide solar array area (spinning configuration), boom mounting locations, payload equipment installation and payload sensor mounting. This arrangement allows considerable design flexibility and adaptability. Specific mission studies, described below, have verified the modularity features of the basic design.

FIGURE 1  
BOEING SMALL VEHICLE HISTORY

<u>YEAR</u>	<u>PROGRAM</u>	<u>NUMBER OF VEHICLES</u>	<u>COST</u>	<u>FIRST DELIV.</u>	<u>FLIGHT HISTORY</u>
1964	BURNER II	12	\$1.1M EACH	12 MO	12 FOR 12
1967	BURNER IIA	8	1.2M EACH	12 MO	8 FOR 8
1967	SESP 67-1	1	.25M	4 MO	SUCCESS
1968	SESP 68-1	1	4.0M	11 MO	FAIRING FAILED
1969	STP 70-1	1	1.7M	13 MO	SUCCESS
1971	STP 72-1	1	6.4M	18 MO	SUCCESS
1972	STP S3	3	3.7M EACH	24 MO	3 FOR 3
1975	AEM BASE MOD.	2	3.8M EACH	21 MO	2 FOR 2
1980	VIKING BUS	1	8.1M	28 MO	(1985)

FIGURE 2  
Platform General Arrangement

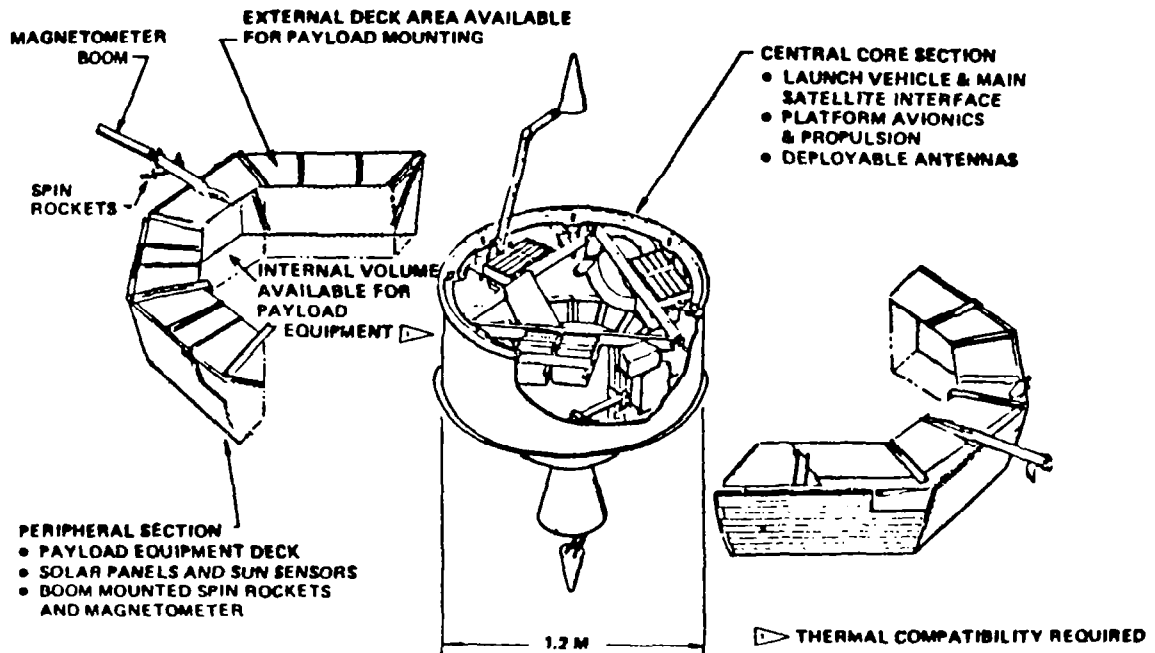


Figure 3 summarizes the subsystem features for the spin stabilized version. While these are the basic performance capabilities, other requirements can easily be met with variations of flight proven equipment or subsystems. For example, a 3-axis attitude control subsystem can be provided by adding the standard Ithaco momentum bias hardware. Control to  $+0.5^\circ$  in pitch and roll and  $+1^\circ$  in yaw can thus be provided. Also, telemetry equipment and antennas can be easily changed to suit specific mission needs. Solar array area and batteries can be added and the solar array can be paddle mounted and articulated if necessary.

To keep costs low, existing equipment and subsystems have been proposed for studied mission applications. A typical equipment complement is summarized in Figure 4. The supplier and space vehicle heritage is shown for the items being flown on the Swedish Viking version of MESA.

Mission Applicability. By providing considerable modularity and emphasizing a simple, flexible design, we have been able to show considerable adaptability to a variety of low cost science and applications missions. Figure 5 lists some typical programs studied and Figures 6 and 7 summarize specific missions as examples.

The Viking program, being funded by the Swedish Space Corporation, continues the long term work on auroral phenomenon conducted by various Scandinavian scientific investigators using sounding rockets. The orbit has a high apogee, placed over Sweden initially, that carries the spacecraft through the auroral zones. The mission life specified is very short (six months), so the spacecraft is essentially a single thread design. Science and housekeeping data is transmitted by S-Band to the Swedish ESRANGE ground station at 55 Kbps and 833 bps respectively.

Boeing has studied the application of the MESA bus to the SARSAT (Search and Rescue Satellite) program in detail including a \$50,000 funded study with CNES. The French are interested in a joint search and rescue/data collection system summarized in Figure 7. Since procurement of an American satellite would be difficult for a French program, Boeing has signed an agreement with MATRA that provides for joint MESA marketing activities for ESA missions and for MATRA to be prime contractor in the event of any hardware contract.

The specific MESA version developed for the French SARSAT/POST-ARGOS mission is shown in Figure 8. The spacecraft is 3-axis stabilized and the drawing shows the installation of the Ithaco subsystem mentioned earlier. The design life is extended to 5-years through selected redundancy in critical areas.

Launch Options. The basic MESA platform was designed for the Ariane booster, since the Swedes are part of ESA. Figure 9 shows on the left, MESA as a secondary payload mounted under the primary Ariane spacecraft. The central core of MESA is qualified to carry the full Ariane primary payload weight during boost. As shown on the right, MESA spacecraft can also be stacked one on the other to launch a cluster of vehicles, for a SARSAT program as an example, with a single Ariane launch.

FIGURE 3

## Platform Design Summary



### ATTITUDE CONTROL

SPIN STABILIZED USING EARTH/SUN  
SENSORS AND MAGNETIC TORQUEING  
3 RPM SPIN RATE  
 $< \pm 1$  DEGREE CONTROL ACCURACY  
MAGNETIC TORQUEING BELOW 4000 KM

### TELEMETRY, TRACKING AND COMMAND

S-BAND/ESA COMPATIBLE  
CONVOLUTIONAL CODING (UNCODED  
OPTIONAL)  
ESA/GSTDN TONE RANGING  
85 KBPS HIGH RATE DATA  
863 BPS LOW RATE ENGINEERING  
DATA  
128 HIGH/LOW LEVEL COMMANDS  
SPHERICAL ANTENNA COVERAGE

### POWER

28  $\pm$  4 VDC SOLAR ARRAY/BATTERY  
122 W ORBIT PEAK  
80 W ORBIT AVERAGE  
2.2 M<sup>2</sup> FIXED SOLAR ARRAY  
12 AMP-HR BATTERY

### PROPULSION

TE-M-442-2 SOLID PROPELLANT ORBIT  
ADJUST MOTOR  
36,800 N THRUST  
621,800 N-S TOTAL IMPULSE  
MARC 3881 SOLID PROPELLANT SPIN/  
DESPIN MOTORS  
382 N THRUST  
300 N-S TOTAL IMPULSE

### THERMAL CONTROL

PASSIVE/MULTILAYER INSULATION,  
RADIATORS AND LOUVERS

FIGURE 4

## Hardware Derivation /Design Base Summary

Structure	(Boeing) New
Cable Harness	(Boeing) New
Pinpullers	(SOS) Various Flight Programs
S-Band Antenna	(Boeing) S3, HCMM, SAGE, IUS
TLM Encoder	SAAB FE
CMD Decoder	SAAB FE
Transponder	SAAB FE
Coaxial Switch	(TRANSCO) Classified
Timer/Sequencer	(CYCLOMATIC) S3, HCMM, SAGE
Rocket Motor	(Thiokol) DOT
Spin/Despin Motors	(Atlantic Research) S3
Louvers	(Northrop) Mariner 10, S3, HCMM, SAGE
Thermal Blankets	(Boeing) Mariner 10, S3, HCMM, SAGE
Amphere-hour Meter	(Gulton) S3
Voltage Limiter	(Gulton) S3
Battery	(Philco-Ford) INSAT
Solar Panels	(Spectro Lab) New
Relay Box	(Boeing) New
DC-DC Converter	(ATC) Various
Sun Sensor	(ADCOLE) HCMM, SAGE
Earth Sensor	(ITHACO) SEASAT, 78-2
Nutation Damper	(Boeing) S3
Electromagnets	(ITHACO) HCMM
Interface Control Elec	(Boeing) New

FIGURE 5

## Typical MESA Missions

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- Viewing of the Earth from Space
- Viewing of the upper atmosphere of the Earth
- Relaying communications between Earth stations
- Viewing of natural phenomenon from above the Earth's atmosphere including that related to other celestial objects
- Collecting and relaying data from Earth-based transmitters
- Carrying small objects into Space for purpose of testing

FIGURE 6

## Viking Scientific Mission



---

### OBJECTIVE

- Investigate interaction between hot and cold plasmas along auroral field lines

### SCIENTIFIC EXPERIMENTS

- Electric Field – Sweden, Royal Institute of Technology
- Magnetic Field – US, John Hopkins University/ONR
- Particle Experiment – Sweden, Kiruna Geophysics Institute
- Plasma Wave Experiment – Sweden, Uppsala Observatory;  
Denmark, Space Research Institute;  
France, Centre de Recherches en  
Physique
- UV Images – Canada, York University

FIGURE 7

## SARSAT/POST-ARGOS Mission



- Prompt detection and localization of distressed units
- \$50K study with CNES to evaluate feasibility of MESA platform as satellite component
- Memorandum of Understanding with MATRA:
  - Joint investigation of potential European missions applicable to MESA
  - MATRA will serve as prime contractor
- SARSAT/POST-ARGOS: combines search and rescue with a data collection system:
  - Basic MESA bus: Boeing
  - Instrument module and integration: MATRA
  - Telemetry subsystem: Thomson, Crouzet, SAAB
  - Other potential European suppliers

FIGURE 8

## SARSAT/Post-ARGOS Platform Summary



<b>MISSION:</b>	<b>COMBINES SEARCH AND RESCUE FUNCTION WITH A DATA COLLECTION SYSTEM</b>
<b>MASS:</b>	<b>480 KG</b>
<b>POWER:</b>	<b>130 WATT AVERAGE</b>
<b>LIFETIME:</b>	<b>5 YEARS</b>
<b>LAUNCH:</b>	<b>SHARED ARIANE</b>
<b>STABILIZATION:</b>	<b>3-AXIS, REACTION WHEEL WITH MAGNETICS</b>
<b>SIZE:</b>	<b>OCTAGONAL DECK, 2 METERS ACROSS FLATS</b>
<b>FREQUENCIES:</b>	<b>121.5/243/406 AND 401.8 MHZ UPLINKS</b>
<b>ORBIT:</b>	<b>1000 - 1200 KM CIRCULAR QUASI-POLAR CONSTELLATION (4 OR 8 SPACECRAFT)</b>

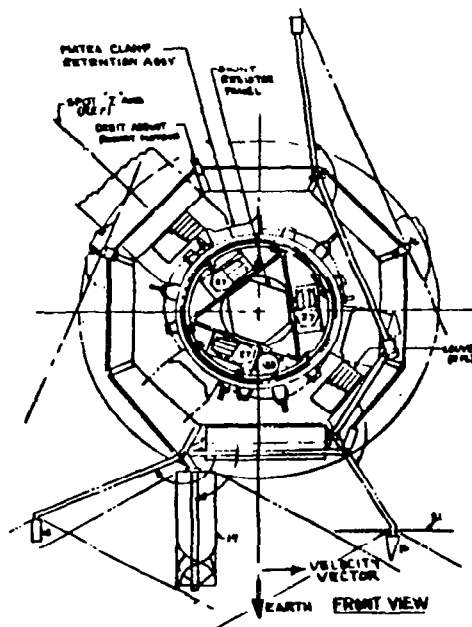


FIGURE 9

# Various Launch Configurations Available

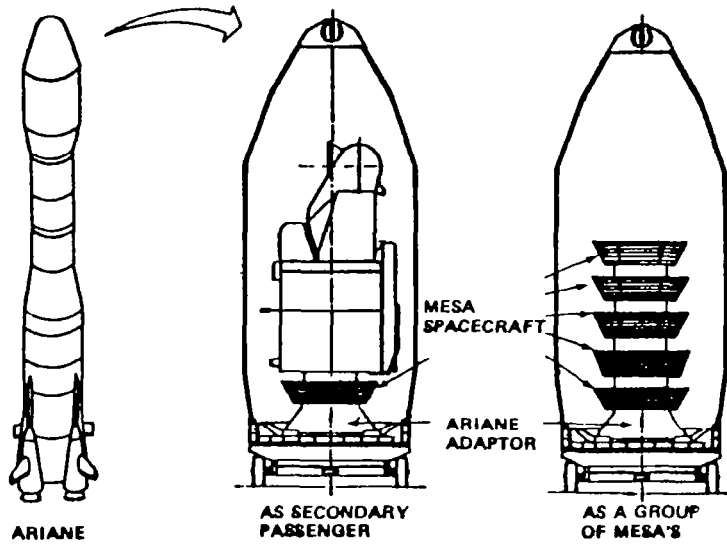
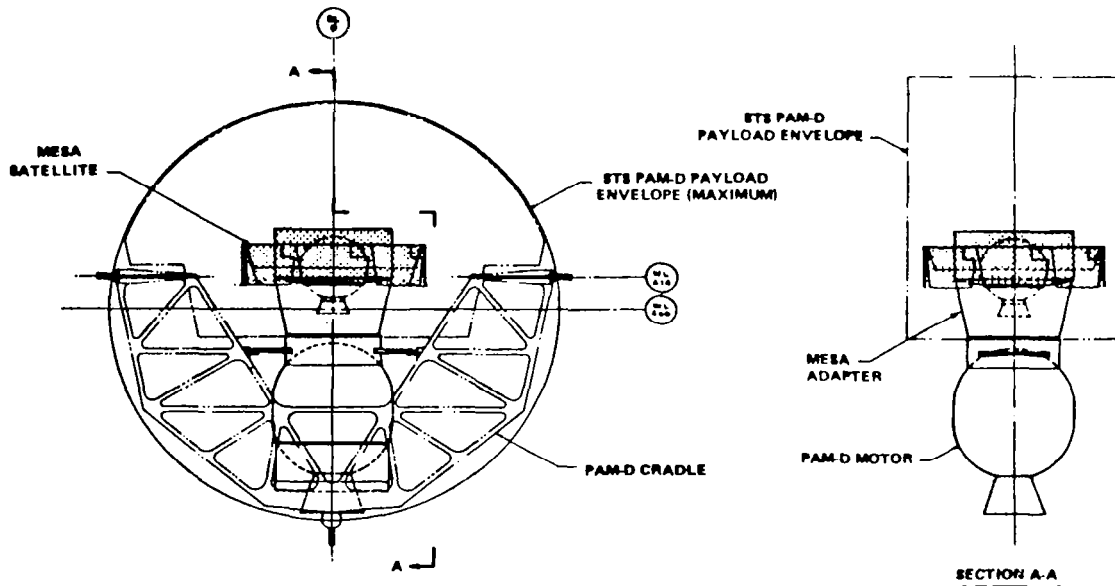


FIGURE 10

# MESA Bus on PAM-D





Although originally designed for Ariane, MESA can be launched on the Shuttle by using a suitable upper stage. Figure 10 shows the adaptation to the PAM-D. Other upper stages have been investigated and there are no interface or functional problems with these concepts. All adaptations reviewed to date verify the feasibility of our modular, low cost design approach.

Because the envelope of the Ariane (and Shuttle, of course) payload volumes are quite large, the MESA can be modified to a number of configuration concepts without affecting the primary structure and the general house-keeping equipment installations. Some typical designs (related to specific missions under study) are shown in Figure 11. They all conform to the allotted Ariane envelope, shown on the left, and the Shuttle/PAM-D envelope depicted in the previous figure.

Low Cost Features. The very low cost of the Boeing small spacecraft systems is due partly to the simplicity of the missions flown, short mission design lives and state-of-the-art technology generally used. However, there are some specific management and design philosophies used that are directly responsible for our low cost performance. Figure 12 summarizes key management approaches.

First, it's important that the organizational structure suit the program philosophy. We do not use many management tiers and we insist on using only experienced, multi-skilled engineers and technicians. By keeping such a small, experienced team we have been able to develop a strong team spirit that we deliberately exploit and expand into the experimenter and customer organizations.

With a small team and a close working relationship with other agencies, we can reduce the normal degree of program formality, documentation and design reviews that are costly contributions to a spacecraft program. Our experience is that by developing a strong team spirit at the working level, experimenter and customer agencies have a high degree of confidence and enthusiastically support our management approach.

A key program cost driver are the subcontractors and suppliers. They must be indoctrinated and continually monitored for compliance with our low cost philosophies. We flow down the "team spirit" attitudes, lack of formality, small amount of documentation, design reviews, etc. into their involvement as well. This is somewhat unconventional and many suppliers are skeptical at first, but we have developed a set of subcontractors over the span of these programs that support us very well. A key problem to them is our small quantity procurements (often only one unit) so it's important we remain as little a burden to them as possible.

Finally, an extremely important consideration is the discouragement (ideally the elimination) of changes after a program is underway. A conventional philosophy often perceived is that contractors like changes because it adds big ECP's to their acquisitions. On small, low cost, often fixed price, one-of-a-kind spacecraft programs, changes can be a cost and schedule disaster. For one thing, it is not possible to really comprehend the impact of a change when it is first conceived and unless the resulting ECP is deliberately overpriced, the contractor often loses money in the final analysis. Also, schedule delays and slides, vehicle rework, subcontractor changes, etc. add considerable program cost even for very minor changes. It is imperative

FIGURE 11

## Configuration Options Compatible with Piggyback Envelope

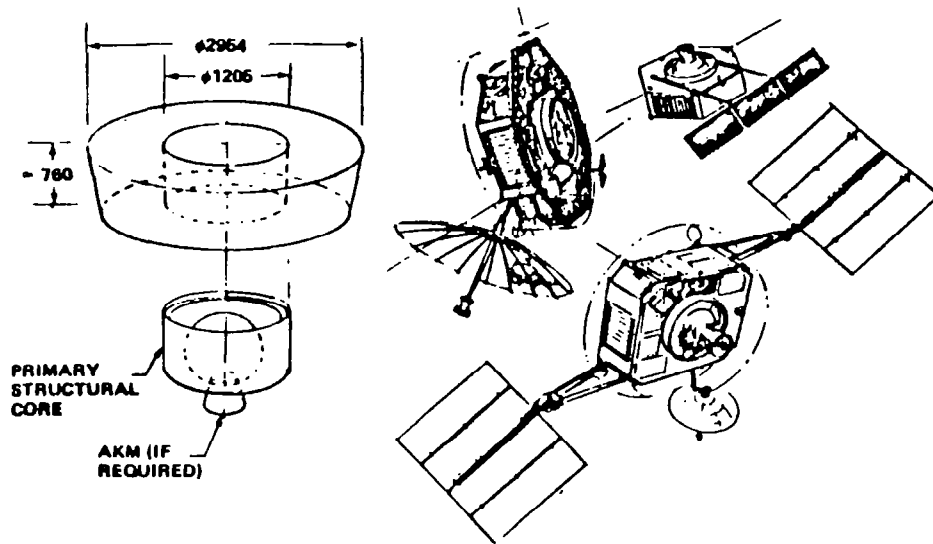


FIGURE 12

### LOW COST MANAGEMENT APPROACH

- A SMALL, EXPERIENCED, MULTI-SKILLED ORGANIZATION:
  - "CONTRACTOR-GOVERNMENT-EXPERIMENTER TEAM" ATTITUDE
  
- A MINIMUM OF FORMALITIES, DOCUMENTATION, DESIGN REVIEW POINTS AND "ILITY" INVOLVEMENT
  
- PROPERLY INDOCTRINATED AND COOPERATIVE SUBCONTRACTORS
  
- DISCOURAGEMENT OF CHANGES:
  - FROM CUSTOMER AND EXPERIMENTER
  - BY DESIGN TEAM

that the entire program team, the customer, experimenter, suppliers as well as the design engineers, recognize the severe potential cost impact of changes and keep them to an absolute minimum. We have a posted motto to help instill this philosophy: "Don't make it better, make it work."

Similar philosophies are carried over into the engineering activities associated with these low cost programs (Figure 13). The first step in ensuring we can achieve a low cost design is to identify the program requirements that are costly and then challenge them. Very often in our experience an experimenter doesn't understand the impact of what he wants until it is explained to him. He can often make trade-offs and reduce his requirements. One very typical problem is attitude (pointing) control. Most experimenters ask for very tight pointing. Our experience is that they can almost always accommodate looser pointing if they have accurate attitude determination suitably time-tagged and recorded or transmitted. In their data reduction process, the attitude determination data is used to update and "correct" the attitude control data to obtain what is the equivalent of precise experiment results. It is easier and much less costly to get attitude determination data through earth and sun sensors than to achieve accurate pointing control in space. There are other similar trade-offs to make when one is trying to optimize spacecraft subsystems for cost.

As mentioned earlier, we have developed a set of compatible and cooperative suppliers and we tend to go back to them continually to reuse the same equipment with which we are familiar and for which the supplier has existing designs, tooling, test procedures, etc. This "off-the-shelf" equipment set is proposed to our new potential users although it is often what everybody considers old technology. When necessary, we fly new designs, but don't get into new developments just to save a little weight or improve efficiency. This approach is another difficult attitude for some engineers and customers to adopt but it is possible to show documented significant cost savings to a program.

Low cost "designs" are a difficult concept to comprehend but is a key element of our approach. A low cost design is one with a high degree of producibility, testability, maintainability, accessibility and reliability (through simplicity). Some designers can achieve this, others cannot. To develop this trait we work very closely with the manufacturing and test personnel (team spirit again) who will be assigned to these spacecraft. This coordination starts at the very beginning of the program and our engineers are instructed to listen to and respond to the suggestions, criticisms and comments provided by these organizations. The point made about few machined parts should be mentioned; any complex machining operation, especially on small quantities, is expensive. We work hard to ensure structural joints are simple and can be made without machined parts where possible. Intuitively, it would seem that this would cause a structural weight penalty, and it probably does, but our experience is that it is very small and this approach has never gotten us into an adverse program weight problem.

Just as we want an experienced engineering team with program-to-program continuity, we strive for the same with support organizations such as Finance, Contracts, Materiel, etc. We use a "dedicated" fabrication and test facility, rather than meshing into the large Boeing production facilities, just to ensure we can monitor and control those activities. We in-

FIGURE 13  
LOW COST DESIGN APPROACH

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- CONTINUOUS CHALLENGING OF REQUIREMENTS
- EXTENSIVE USE OF FLIGHT PROVEN, OFF-THE-SHELF EQUIPMENT
- LOW COST DESIGNS REQUIRING:
  - SIMPLE TESTING
  - SIMPLE TOOLING
  - FEW MACHINES PARTS
- DEDICATED SHOP, MATERIEL AND FINANCE SUPPORT:
  - QUICK REACTION, LOW COST
- PROTOFLIGHT TEST CONCEPT EMPHASIZING:
  - EXPECTED MISSION CONDITIONS
  - INTERFACES
  - SYSTEM LEVEL

FIGURE 14  
**Summary**

- Boeing has demonstrated that small, simple spacecraft can be produced at low cost.
- Low cost does not mean low reliability:  
 $27/28 = 96.4\%$  success
- With the advent of space commercialization low cost approaches become even more important.

sist on experienced, multi-skilled personnel in these organizations also and have been successful in keeping the same cadre of manufacturing and test people on our programs for many years. Such an approach allows us to efficiently respond to customer requests, new program initiatives and other marketing activities. We can get a new program going very quickly.

The testing philosophy associated with these low cost programs emphasizes a "protoflight" concept. That is, we build one vehicle to test and fly. By environmental testing to qualification levels for acceptance durations we don't over-stress the vehicle structure or equipment. We do not introduce program risk by this approach but do save considerable cost. Associated with this approach, we carefully structure our test programs to emphasize expected mission conditions (rather than test to "discover" actual margins). We also emphasize interfaces with the payloads, booster and ground stations as these are often critical operational weak points. Finally, although many programs use multilevel testing such as that required in the new MIL-STD-1540A for example, we have kept our focus on system level testing to shorten schedules, reduce stress on our protoflight vehicles and drastically reduce test costs. There are considerable arguments to be raised for and against this testing philosophy but our experience shows us that for small, low-cost programs, we can expect a high degree of success with this approach. We continue to make trade-offs on all new programs and carefully consider the cost-effectiveness of protoflight testing.

Summary. There are three specific points to be made in summarizing the MESA concept (Figure 14):

First, we have demonstrated for almost two decades that small, low-cost space vehicles are a reality. Admittedly, it is a small and unique market and we do not presume to imply that all space programs are suitable for the approaches discussed herein. Nevertheless, for the class of vehicles of a few hundred pounds and for simple, scientific and/or applications missions, there is no question that small space vehicles can be produced for costs in the neighborhood of \$10M at today's prices.

We have also demonstrated that low cost does not mean poor reliability. The cost savings are achieved by eliminating and/or controlling program characteristics that are not cost-effective, not by eliminating tasks that are necessary. In other words, we don't do anything that is not necessary, but what is necessary we do extremely well. People have been critical of low cost programs because of a mistaken belief that the product is "cheap" by definition. That is absolutely not the case. Reliability is achieved by simple designs by an experienced design team using flight proven concepts and equipment. Low cost approaches, as we define and use them, do not compromise these factors and therefore, do not compromise product reliability.

An important final point, in our judgment, is that if low cost was important to government programs, it is even more important in commercial programs where considerable financial investment from private sources is at risk. Factors such as return on investment, cash flow, revenue sources and competition are coming into play more and more. We believe we are well positioned to adapt to these characteristics with our decades of demonstrated low cost experience.

**EUROPEAN RETRIEVABLE CARRIER (EURECA)  
AN EVOLUTIONARY SPACE CARRIER FOR MICROGRAVITY, EARTH  
OBSERVATION AND TECHNOLOGY DEMONSTRATION**

by

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**ABSTRACT**

The experience gained by Europe in the Spacelab development programme, and the specific needs of the user world for extended mission duration under microgravity conditions, have led Europe to follow an approach responsive to its own needs.

The approach to space platforms can be regarded as involving three step viz Spacelab, EURECA and Space Station.

The Spacelab relatively short stay-time in orbit has led to consideration of the EURECA concept as a reusable carrier. The EURECA concept is a free-flying retrievable carrier of experiments which is launched and recovered by the Space Shuttle. EURECA is commensurate with the size of payloads that can be economically developed in Europe. EURECA combines the advantages of Spacelab (high mass and power capability, recovery) with those of a free flyer (extended operating time in a non-polluted environment).

The launch of the first EURECA mission is scheduled for October 1987. The EURECA spacecraft will be deployed from the Shuttle cargo bay in orbit, will operate in a free-flying mode for about six months, and will then be retrieved, together with its payloads, returned to Earth by the Space Shuttle and prepared for the next mission. The financial envelope, enabling work to start in 1982, covers the development of the carrier and of the core payload dedicated to microgravity research, the integration, the launch and the retrieval of EURECA.

The first mission of EURECA is dedicated to research in the fields of life sciences and material sciences. The experimental hardware of the first mission will consist of a variety of processing chambers for crystal growth and equipment for biological investigations viz plant growth and protein crystallisation, and there is the possibility to perform experiments in the field of exobiology.

The experimental hardware selected for the first EURECA mission consists mainly of a so-called 'core payload' to be provided by ESA. Six multi-user facilities will allow the processing of metallurgical samples, crystal growth from the melt and from high- and low-temperature solutions, as well as biological and biochemical investigations (plant growth in a low-gravity environment, protein crystallisation, etc.). In addition, there will be two categories of experimenter-supplied 'add-on' hardware, one from the fields of material sciences and life sciences, and a second from other disciplines, such as space science and technology. Later missions of EURECA will be dedicated to space science, Earth observation and technology investigations.

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\*Paper presented by G. Seibert.

## I. INTRODUCTION

Since almost 10 years, the level of involvement of the European Space Agency in the very promising field of material and life sciences in space has been constantly increased. Future activities seem to be even better, due to the fact that nearly all European scientists :

- . are now fully aware of the basic interest in research in the microgravity environment;

- . are vigorously building real European microgravity research cooperation that allows all the individual efforts to be optimised, and at last

- . are convinced of the importance of microgravity phenomena, some of which may allow to extrapolate to future applications and space industrialisation.

(Fig. 1)

The initial "microgravity" involvement in Europe was centered around experimentation on the first Spacelab mission which offered a king portion to microgravity research in terms of power resources and operation in orbit.

With the successful maiden flight of the first mission of Spacelab (the most significant payload of the orbiter), a new area in space flight began. Operation of the reusable space transportation system, together with refllyable Spacelab payloads, open up new perspectives for space flight and bring industrial exploitation of space within striking distance.

The large capability of Spacelab means that Spacelab flights are for cost reasons not very frequent. This leads to long waiting periods for prospective space experimenters and a reluctance to fund a Spacelab flight. This fact, together with Spacelab's relatively short stay-time in orbit has led to the EURECA concept.

## II. KEY ADVANTAGES FOR SPACELAB/SORTIE MODE INSTRUMENTS ON EURECA

In developing the EURECA concept, flexibility was a mandatory requirement in order to accommodate a wide variety of payloads and to provide key advantages regarding resources for Spacelab instruments on EURECA.

(Fig. 2)

ESA's Member States approved in 1982 the development of a retrievable space platform and a group of experimental facilities dedicated to scientific experimentation in a very low-acceleration ("microgravity") environment. The European Retrievable Carrier, or EURECA for short, will be launched on its maiden-flight in 1987 by the Space Shuttle. It will be retrieved and returned to Earth after some six months in orbit. This flight will be the first of a series of medium-to long-duration space missions, planned to occur at approximately two-yearly intervals.

### III. EURECA FLIGHT SCENARIO

(Fig. 3)

A typical EURECA mission calls for the carrier's launch by the Shuttle, removal from its cargo-bay by means of the Remote Manipulator System, and subsequent release. Once the Orbiter has moved to a safe distance, EURECA will be activated and checked. If all is well an Orbit Transfer Manoeuvre (OTM) from deployment- to operating altitude will be initiated.

An in-orbit stay of approximately six months is scheduled for the experiment operations. The return to Earth will take place as soon as possible after completion of the experiments, but waiting ("dormant") periods of several weeks or even months may occur, depending on the Shuttle's flight schedule.

Retrieval will commence with a descent OTM. Rendezvous and docking operations will be performed by the Shuttle with EURECA as a cooperative, passive target. Following deactivation, EURECA will then be re-stowed in the Orbiter cargo-bay for return to Earth.

### IV. EURECA PROGRAMME OBJECTIVES

The programme objectives for the development of the EURECA system are the following :

(Fig. 4)

### V. THE EURECA PLATFORM AND ITS MISSION

Approximately 2.5 m long and weighing about 3.5 tonnes, EURECA will be a fairly heavy space vehicle. Fully equipped, it will fill the cross section of the Shuttle's cargo bay.

(Fig. 5)

It has been conceived with a high degree of flexibility and growth-potential in mind, and its design incorporates the ability to accommodate and support a wide range of payloads beyond those dedicated to microgravity research.

EURECA will have the same kind of subsystems as a comparable nonretrievable Earth satellite, for :

- . structural integrity
- . thermal control
- . power generation and distribution
- . data management and telecommunication
- . attitude control.

In addition, however, EURECA will be equipped with a novel Orbit-Control Subsystem (OCS). A mono-propellant system with a 20 N thruster and tanks containing sufficient propellant for a total velocity change to allow the carrier to lift itself from its Shuttle deployment



orbit (about 300 km) to altitudes compatible with the atmospheric drag and orbit-decay requirements of the microgravity mission (about 500 km). The OCS will be used again at the end of orbital operations to reach retrieval orbit and rendez-vous with the Shuttle.

EURECA will have the same kind of subsystems as a comparable Earth satellite as described in Fig. 6 and 7, 8 and 9 below.

(Fig. 6, 7, 8, 9)

## VI. PAYLOAD FOR THE FIRST EURECA MISSION

The first mission of EURECA is dedicated to research in the field of life sciences and material sciences.

The EURECA mission offers also the opportunity for long-time exposure of materials of terrestrial origine to the unique environment of space, such as the radiation environment, the space vacuum, extreme temperatures and microgravity conditions.

The core payload of EURECA consists of 5 multi-user facilities as listed in Fig. 10.

(Fig. 10)

### Automatic Mono-ellipsoidal Mirror Furnace Facility (AMMFF)

The AMMFF is an optical radiation furnace particularly suited to crystal-growth experiments. Its concept has been derived from similar facilities developed for FSLP (First Spacelab Payload) and D1-Spacelab payloads and from pre-phase-A studies.

The facility design will provide storage room for about 25 samples. A handling and transport mechanism will remove the appropriate sample from its storage location, transport it to the furnace, and expose it to the radiation at selectable values of translational and rotational velocities.

### Solution Growth Facility (SGF)

The SGF is essentially a set of "reactors" for diffusion controlled crystal growth from solutions. Its concept has been derived from similar facilities developed for FSLP and the NASA Long-Duration Exposure Facility (LDEF).

Each reactor consists of two reactant reservoirs and a solvent chamber, interconnected via special valves, operation of which must create a minimum of turbulence in the liquids.

### Protein Crystallisation Facility (PCF)

The PCF will enable investigators to perform protein crystallisation experiments in space. Its concept has been derived from the FSLP Cryostat Experiment.

The design employs 12 identical reactor vessels which provide an individually controlled temperature environment for each of the 12 samples. Each vessel will consist of three adjacent chambers, carrying an enzyme-, a salt-, and a buffer-solution, respectively. These chambers can be physically interconnected by remote control. Protein crystallisation is initiated by allowing the enzyme- and salt-chamber solutions to diffuse into the reaction chamber.

Processing times in the order of 60 days are planned. Progress in crystal growth can be observed on the ground by means of a video camera.

#### Multi-Furnace Assembly (MFA)

The MFA is intended to provide a modular payload dedicated to materials-science experiments by grouping 10-12 furnaces with common subsystem interfaces. It will be possible to reuse furnaces already developed for other purposes, such as sounding-rocket flights.

The furnaces, with their samples and sensors, will be specific to one research topic and the MFA will provide common equipment and services for the different types of furnace. The normal operating environment will be space vacuum : certain furnaces may, however, be pressurised at the user's request.

The MFA will normally be operated in a fully automatic mode, but a facility for reprogramming from the ground is envisaged. Monitoring of furnace data as well as commanding and reprogramming of the facility is to be accomplished via the EURECA communications links.

#### Botany Facility (BF)

The BF is proposed as a multi-user life-sciences facility, intended to support investigations into the zero-g behaviour of higher plants and fungi. It will consist of an experiment module, which is effectively a single temperature-controlled chamber to contain all experiment equipment and samples. The BF provides life support, illumination, data handling, etc. A video system will provide two-dimensional or stereoscopic images of the biological specimens inside the chamber.

### VII. FUTURE IN-ORBIT INFRASTRUCTURE DEMONSTRATION

ESA expects the approval of EURECA missions beyond the first flight. The demonstration of important technologies, such as the rendez-vous of satellites, the docking and undocking and the operation of payload manipulators shall be performed. As indicated on Fig. 11, it is planned to link EURECA-I with L-Sat (an ESA communication satellite) as a precursor to a future operational European relay system.

(Fig. 11)

The growth capabilities of the EURECA system are indicated on Fig. 12 :

(Fig. 12)

... and for technology demonstration, on Fig. 13 :

(Fig. 13)

A modular set of hardware and software elements will be provided that will allow to assemble a number of dedicated platforms.

(Fig. 14)

## VIII CONCLUDING REMARKS

The EURECA platform, making use of current technology, is a significant and innovative step forward in space research and industrialisation.

Detailed design work on this initial EURECA platform is almost completed. The development phase will be initiated in June 1984 for a duration of about 40 months.

EURECA is intended to complement the Spacelab provided capabilities to longer mission durations and increased resources to the experimenters. Its first flight application will be a microgravity mission in 1987. A EURECA utilisation programme dedicated to microgravity research is planned with a reflight every two years during ten years. New classes of platforms, derived from EURECA, may emerge, such as :

A carrier for non-microgravity disciplines.

A carrier stationed in low-Earth orbit, with the added capability for payloads and products to be exchanged in space. Such a carrier will be compatible with the Shuttle in-orbit maintenance and repair.

A payload carrier system in free-flying mode which could co-orbit or cooperate with a future manned space station.

From the existing concept of EURECA dedicated to microgravity research, which can be considered as a first generation of space platform, future classes of platforms may emerge, depending on the demand.

Fig. 1 : MICROGRAVITY PROGRAMME WITHIN ESA

THE PRIME OBJECTIVES OF MICROGRAVITY PROGRAMME WITHIN ESA ARE :

- (1) ENCOURAGING INTERNATIONAL AND MULTI-DISCIPLINARY COLLABORATION IN BASIC RESEARCH IN ORDER TO EXPLORE THE POTENTIALS OF THE MICROGRAVITY ENVIRONMENT.
- (2) PROMOTION OF USERS' INTEREST BY PROVIDING FLIGHT OPPORTUNITIES, ADVANCED EXPERIMENTAL EQUIPMENT, NEW SPACE TECHNOLOGIES.

... LEADING TO THE FOLLOWING ESSENTIAL TASKS :

- (1) TO UTILISE TO THE MAXIMUM EXTENT BASIC HARDWARE IN EUROPE, SUCH AS MULTI-USER FACILITIES DEVELOPED FOR THE FIRST SPACELAB MISSION.
- (2) TO FACILITATE THE CONCEPTION, DESIGN AND DEVELOPMENT OF NEW EXPERIMENTS.
- (3) TO ENSURE REPEATED FLIGHTS WITHIN THE COMING 10 YEARS (SPACELAB, EURECA, IML MISSIONS).
- (4) TO UNDERTAKE DEFINITION STUDIES FOR BASIC MULTI-USER FACILITIES WHICH WILL BE ABLE TO PREPARE THE SPACE INDUSTRIALISATION IN USING SPACE STATION / SPACE PLATFORM.

Fig. 2 : KEY ADVANTAGES FOR SPACELAB/SORTIE INSTRUMENTS ON EURECA

- . LONGER STAY TIME ON ORBIT (MONTHS VS. DAYS).
- . LOWER COST PER ORBIT-DAY.
- . CLEANER ENVIRONMENT.
- . HIGHER ALTITUDE
- . MORE STABLE PLATFORM.
- . MORE DEDICATED POWER.
- . BETTER AND UNINTERRUPTED MICROGRAVITY ENVIRONMENT.
- . MORE EFFICIENT USE OF SHUTTLE (SHARED FLIGHTS).
- . TWO YEARS TURN AROUND TIME.

Fig. 3 : EURECA FLIGHT SCENARIO

**EURECA**  
European REinevible Carrier

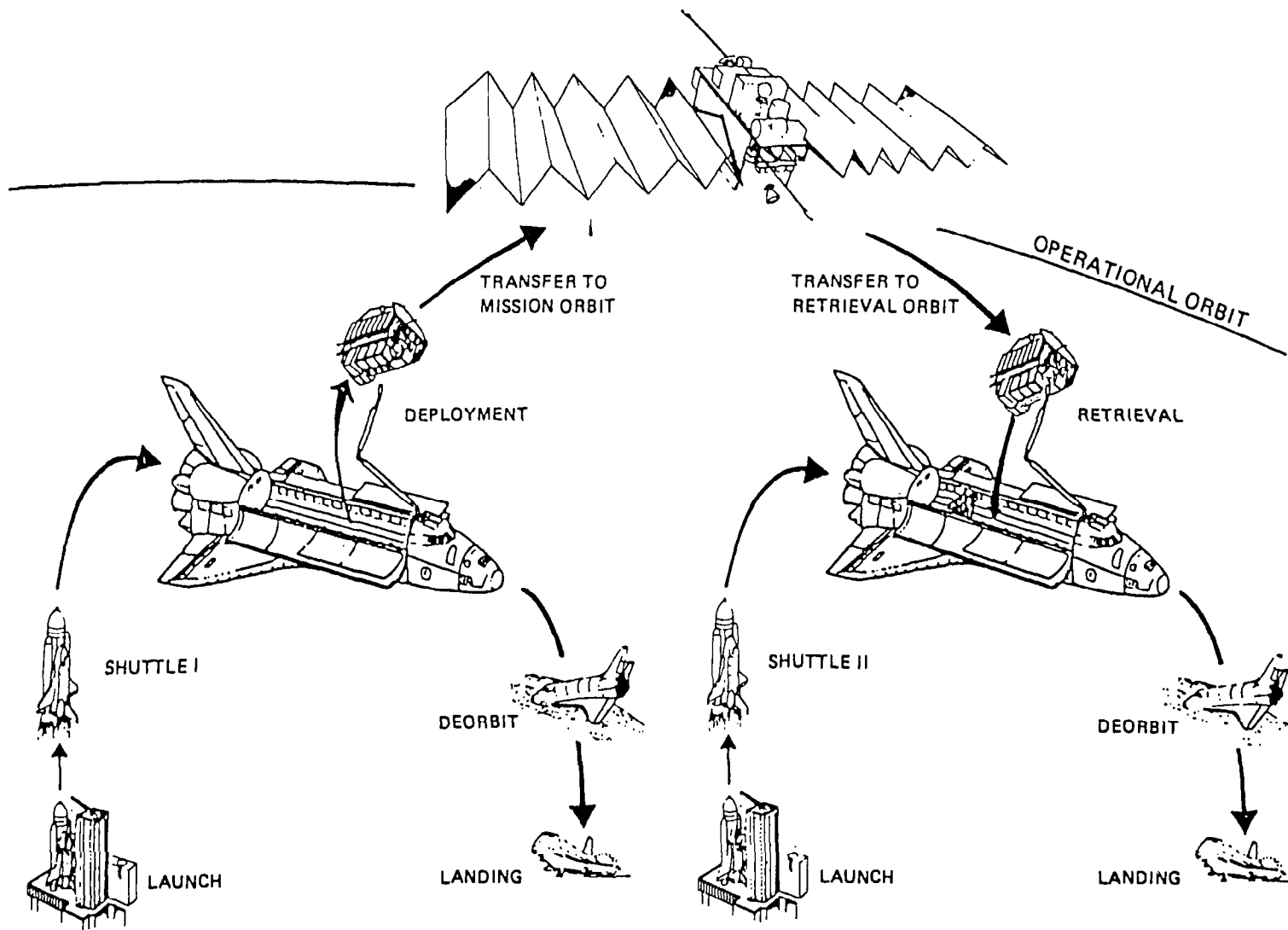


Fig. 4 : EURECA PROGRAMME OBJECTIVES

- EURECA IS THE FIRST RETRIEVABLE/REUSABLE MULTIPURPOSE SPACE PLATFORM UNDER FULL EUROPEAN RESPONSIBILITY
- SCOPED INITIALLY AS AN R&D PLATFORM, PRIMARILY FOR MICROGRAVITY AND TECHNOLOGY DEMONSTRATION, EURECA IS ALSO CONSIDERED ATTRACTIVE FOR OTHER DISCIPLINES
- EURECA IS CONSIDERED TO SATISFY NEAR TERM DEMANDS OF A WIDE USER COMMUNITY FOR PERFORMING SCIENTIFIC AND APPLICATIONS EXPERIMENTS PRIOR TO THE AVAILABILITY OF A SPACE STATION
- THE EURECA CONCEPT DEMONSTRATES THE EUROPEAN CAPABILITY AND AUTONOMY IN DEVELOPING SPACE PLATFORMS

**EURECA**  
European REtrievable CAmer

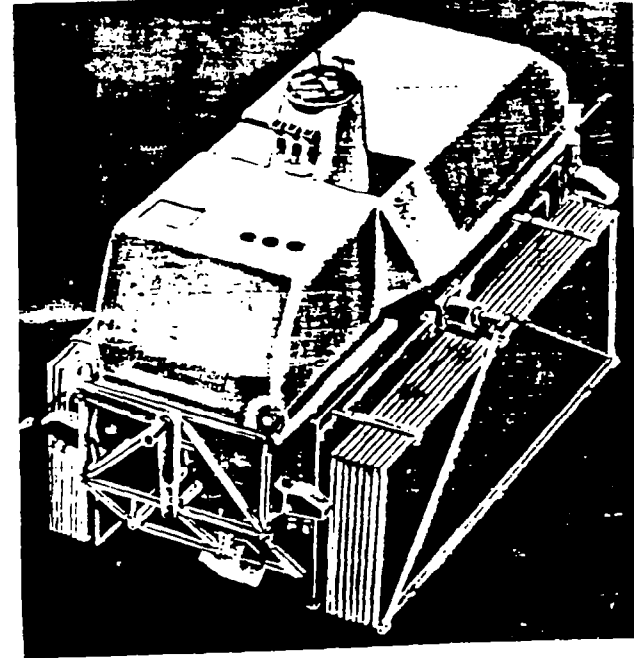
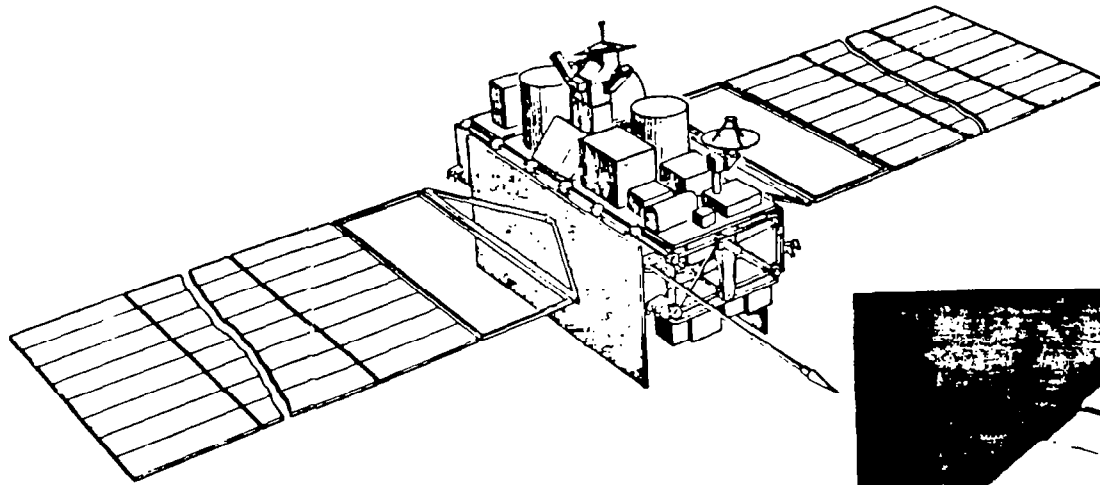


Fig. 5 : EURECA PHASE B CONFIGURATION



Fig. 6 : MAJOR SYSTEM CHARACTERISTICS

- REFERENCE ORBIT 270 NM (500 KM) ALTITUDE, 28.5° INCLINATION
- DEPLOYMENT/RETRIEVAL ORBIT 160 NM (296 KM) ALTITUDE, 28.5° INCLINATION
- EURECA OPERATIONAL MODES :
  - EXPERIMENT OPERATION 6 MONTHS
  - SEMI-DORMANT, UP TO RETRIEVAL BY ORBITER, APPROXIMATELY 3 MONTHS SURVIVAL FOR ANOTHER 9 MONTHS IN CASE OF RETRIEVAL FAILURE
- LIFE TIME : 5 MISSIONS OR 10 YEARS
- MINIMIZE LENGTH IN LAUNCH CONFIGURATION TO MINIMIZE STS COST
- COMPATIBILITY WITH RETRIEVAL BY ORBITER
- COMPATIBILITY WITH STS SAFETY REQUIREMENTS
- OPERABLE FROM EUROPEAN CONTROL FACILITIES

Fig. 7 : MAJOR SYSTEM CHARACTERISTICS (CTD.)

● COMMUNICATIONS

- WITH ORBITER : VIA S-BAND AND PAYLOAD INTERROGATOR (PI)
- WITH GROUND : VIA S-BAND TO ESA GROUND STATIONS

● MANOEUVERS CHANGE OF ORBITAL ALTITUDE, PHASE ANGLE AND PLANE OF ORBIT

● RESOURCES/CAPABILITIES FOR PAYLOADS

- MASS CARRYING CAPABILITY 1200 KG
- CONTINUOUS POWER PROVISIONING 1.7 KW
- DATA RATE CAPABILITY PAYLOAD TO EURECA 2.5 KBPS
- INITIAL POINTING ACCURACY  $\pm 1.0^\circ$  W.R.T. SUN (WITH FINE SUN SENSORS)
- OPERATING TEMPERATURE IN ORBIT  $+ 5^\circ$  TO  $+ 45^\circ\text{C}$
- HEAT DISSIPATION CAPABILITY CONSISTENT WITH POWER LEVEL
- RESIDUAL ACCELERATION IN ORBIT  $10^{-5}$  G BELOW 1 Hz

● TRANSPORTABLE WITH COMMERCIAL AIRCRAFT (B- 747)

● MAXIMUM INTEGRATION IN EUROPE, MINIMUM STAYTIME AT THE LAUNCH SITE  
(SHIP AND SHOOT)

Fig. 8 : SUBSYSTEM CHARACTERISTICS

## ● STRUCTURE

- USES EXISTING HARDWARE AND INTERFACES QUALIFIED FOR STS MISSION
- CAN CARRY A LAUNCH MASS 4000 kg.
- PROVIDES A PAYLOAD MASS CARRYING CAPABILITY OF 1200 kg.

## ● POWER

- DEPLOYABLE, RETRACTABLE AND JETTISONABLE SOLAR ARRAYS 2 x 12 m LONG, SUPPLYING 5.9 kW OF EL. POWER.
- BATTERIES FOR FULL POWER ECLIPSE OPERATIONS AND PEAK POWER CAPABILITY.
- PROVIDES 1.7 kW ELECTRICAL POWER TO THE PAYLOADS.

## ● THERMAL CONTROL

- PROVIDES DIRECT ACTIVE COOLING VIA FLUID LOOP AND RADIATOR FOR DEDICATED PAYLOADS.
- PROVIDES ACTIVE COOLING VIA COLDPLATES FOR BATTERIES AND PAYLOADS.
- USES PASSIVE MULTI-LAYER INSULATION FOR UNIFORM TEMPERATURE LEVEL.
- CONTINUOUS 3.8 kW HEAT REJECTION CAPABILITY.

## ● TELEMETRY/TELECOMMAND

- OMNIDIRECTIONAL S-BAND ANTENNAS FOR COMMUNICATION WITH ORBITER AND ESA GROUND NETWORK.
- DEPLOYABLE RETRACTABLE JETTISONABLE ANTENNAE.

Fig. 9 : SUBSYSTEM CHARACTERISTICS (CONT'D)

- ATTITUDE AND ORBIT CONTROL (AOCs)
  - USES A MONO-PROPELLANT SYSTEM WITH 20 N THRUSTERS FOR COARSE ATTITUDE CONTROL.
  - COLD GAS SYSTEM AND MAGNETIC TORQUERS FOR FINE ATTITUDE CONTROL.
  - THREE-AXIS STABILIZATION AND SUN ORIENTATION USING GYROS, SUN SENSORS, EARTH ALBEDO SENSOR AND MAGNETOTORQUER DURING THE MISSION.
  - USES MACS BUS SYSTEM
  - AUTONOMOUS SAFE MODE FOR EURECA SURVIVAL UNTIL GROUND CONTROLLED RE-INITIALIZATION.
  - APPR. 600 kg PROPELLANT FOR NOMINAL MISSION (6 + 3 MONTHS). 6 TANKS ARE SUFFICIENT
  - 60 kg COLD GAS.
  - INTERNAL REDUNDANCY MANAGEMENT.
  
- DATA HANDLING
  - 2.5 KB/S EXPERIMENT DATA RATE (CONTINUOUS), STORAGE CAPACITY 260 MB.
  - PROVIDES OUTPUT DATA OF 512 KBPS OR 4 KBPS.
  - USES STANDARD OBDH BUS.
  - INTERNAL AUTOMATIC REDUNDANCY MANAGEMENT.
  - SOFTWARE RECONFIGURATION FROM THE GROUND POSSIBLE.
  - PACKET AND STANDARD TELEMETRY/TELECOMMAND.
  
- EGSE
  - CENTRALIZED BUS SYSTEM (LOCAL AREA NETWORK).
  - COMPATIBLE WITH ESA DEVELOPED STANDARDS. USE OF ESA BASIC SOFTWARE (ETOL).
  - USE OF CONTRACTOR SUBSYSTEM TEST EQUIPMENT AS PART OF EGSE.
  
- MGSE
  - OPTIMIZED IN TYPE AND QUANTITY FOR TRANSPORT, INTEGRATION AND TEST AT ERNO, OPERATIONS AT KSC.

Fig. 10 :

**EURECA MISSION 1**  
**Preselected Instruments and Experiments**

CORE PAYLOAD	No of PIS	No of Samples	Sample Material
1. Automatic Mirror Furnace (AMF)	8	24	CdTe, ZnS, ZnTe, Ag/SnO <sub>2</sub> , GaSb, Pb <sub>1-x</sub> Sn <sub>x</sub> Te, Bi <sub>12</sub> SiO <sub>20</sub> , Pb <sub>40</sub> , Ni <sub>40</sub> , P <sub>20</sub> , CdGa <sub>2</sub> S <sub>4</sub>
2. Solution Growth Facility (SGF)	3	15	TTF-TCNQ, CaCO <sub>3</sub> , PbS, TSeF-TCNQ, e.m.f. meas. in electrolyte
3. Protein Crystallisation Fac.	5	12	$\beta$ -galactosidase, Lysozym, Rodopsin, Fibrinogen etc.
4. Multi-Furnace Assembly, MFA	12	up to 19	various alloys and semiconductor growth experiments
5. Botany Facility	9 (7)	6	1 experiment consists of dosimeters Arabidopsis tobacco plants, drosophila
6. Exobiological Radiation Assembly	6	28 deployable + fixed tray	various biological specimen (microorganisms, organic molecules, yeast stains, etc.)
<b>MG-ADD-ON-EXPERIMENTS</b>			
7. High Precision Thermostats (2 off)	2	2	Critical point experiments
8. Surface Forces-Adhesion Meas.	1	1	improved FSLP experiment

In addition, a few space science and technology experiments will be flown.

Fig. 11 : ILLUSTRATION OF THE ESA PROPOSED RVD AND L-SAT COMMUNICATION LINK EXPERIMENT

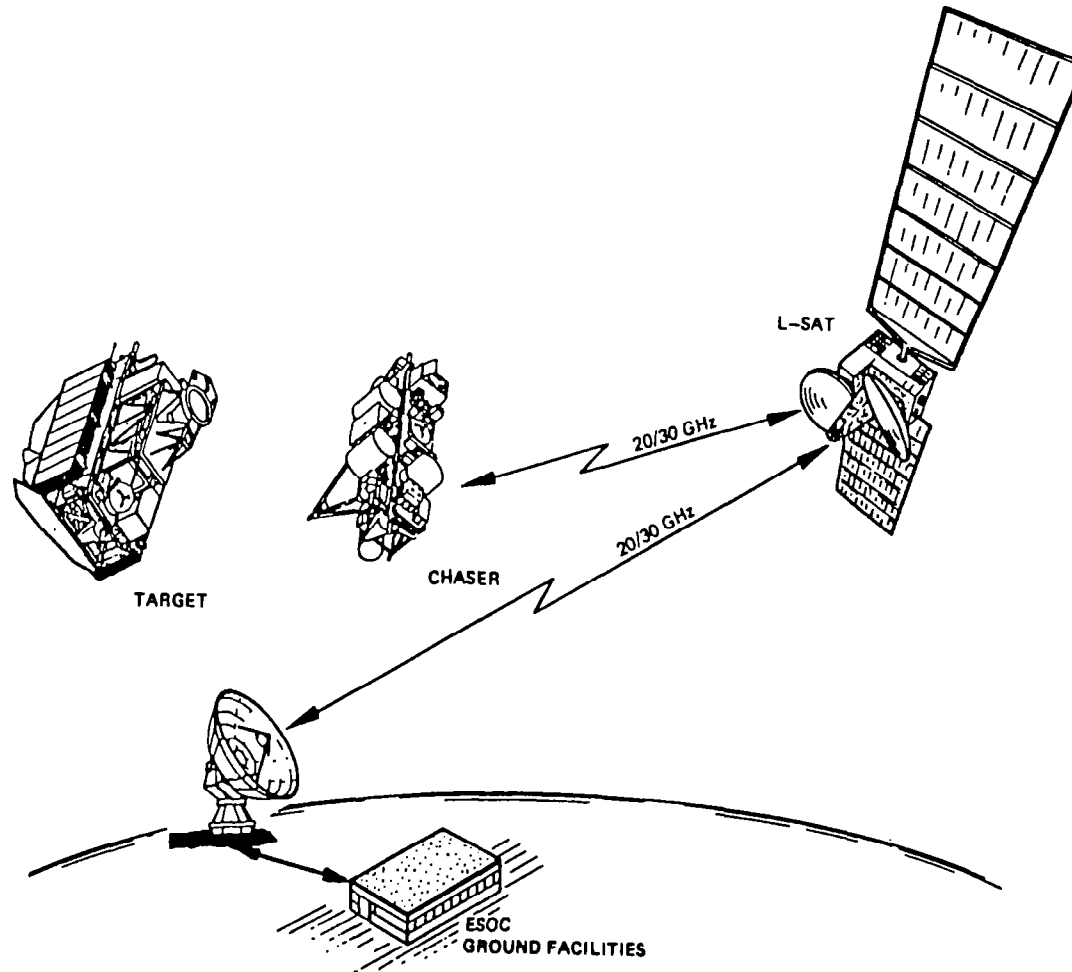


Fig. 12 : EURECA APPLICATION AND GROWTH POTENTIAL FOR SPACE STATION

**EURECA**  
European REtrievable CArrier

POWER

- EXTENSION OF SOLAR ARRAY (2x12 kW)
- POWER STORAGE AND CONDITIONING IN INCREMENTS OF 6 kW BY MULTIPLICATIONS OF BASIC EURECA POWER EQUIPMENT AND ADOPTING A MULTI-POWER BUS CONCEPT LIKE FOR THE FAIRCHILD LEASECRAFT

THERMAL

- EXTENSION OF EURECA LIQUID LOOP/RADIATOR SYSTEM

AOCS

- MACS CONCEPT DIRECTLY APPLICABLE FOR ANY FREE-FLYING SPACE PLATFORM
- ORBITAL PROPULSION CONCEPT DIRECTLY APPLICABLE IF LARGER TANKS AND THRUSTERS ARE SELECTED (SEE FAIRCHILD LEASECRAFT CONCEPT)

AVIONICS

- TTC DIRECTLY APPLICABLE
- DHS DIRECTLY APPLICABLE FOR MODEST ON BOARD DATA HANDLING
- DATA RATES OF MORE THAN ONE MBIT POSSIBLE BY EXTENDING THE L-SAT LINK CAPABILITY OPERATIONALLY

NOTE : EURECA PROVIDES BASIC TECHNOLOGIES AND OPERATIONAL CONCEPTS APPLICABLE FOR THE SPACE STATION SCENARIO; IT NEEDS HOWEVER RECONFIGURATION OF THIS TECHNOLOGY IN SERVICABLE AND MAINTAINABLE MODULES, IF TO BE USED FOR A SPACE BASED AND AUTOMATED SERVICE MODULE (LEASECRAFT CONCEPT)

Fig. 13 : EURECA TECHNOLOGY FALL OUT FOR SPACE STATION

**EURECA**  
European REtrievable CAmer

LEO\_OPS

-NAVIGATION AND ORBIT TRANSFER MANOEUVRES, USING SMALL THRUSTERS TO ATTAIN HIGHER ORBITS AND SUBSEQUENT RENDEZ-VOUS OPERATIONS WITH STS AND SPACE STATION

THERMAL/POWER

-TECHNOLOGY DEMONSTRATION OF HIGH THERMAL/POWER CAPABILITY IN LEO

SIS

-DEMONSTRATION OF DEPLOYMENT (4 TONS) AND RETRIEVAL USING THE STS  
-DEMONSTRATION OF SAFE OPERATIONS WITH STS

AVIONICS

-DEMONSTRATION OF A DISTRIBUTED MICRO-PROCESSOR DATA HANDLING SYSTEM WITH SIGNIFICANT GROWTH CAPABILITY

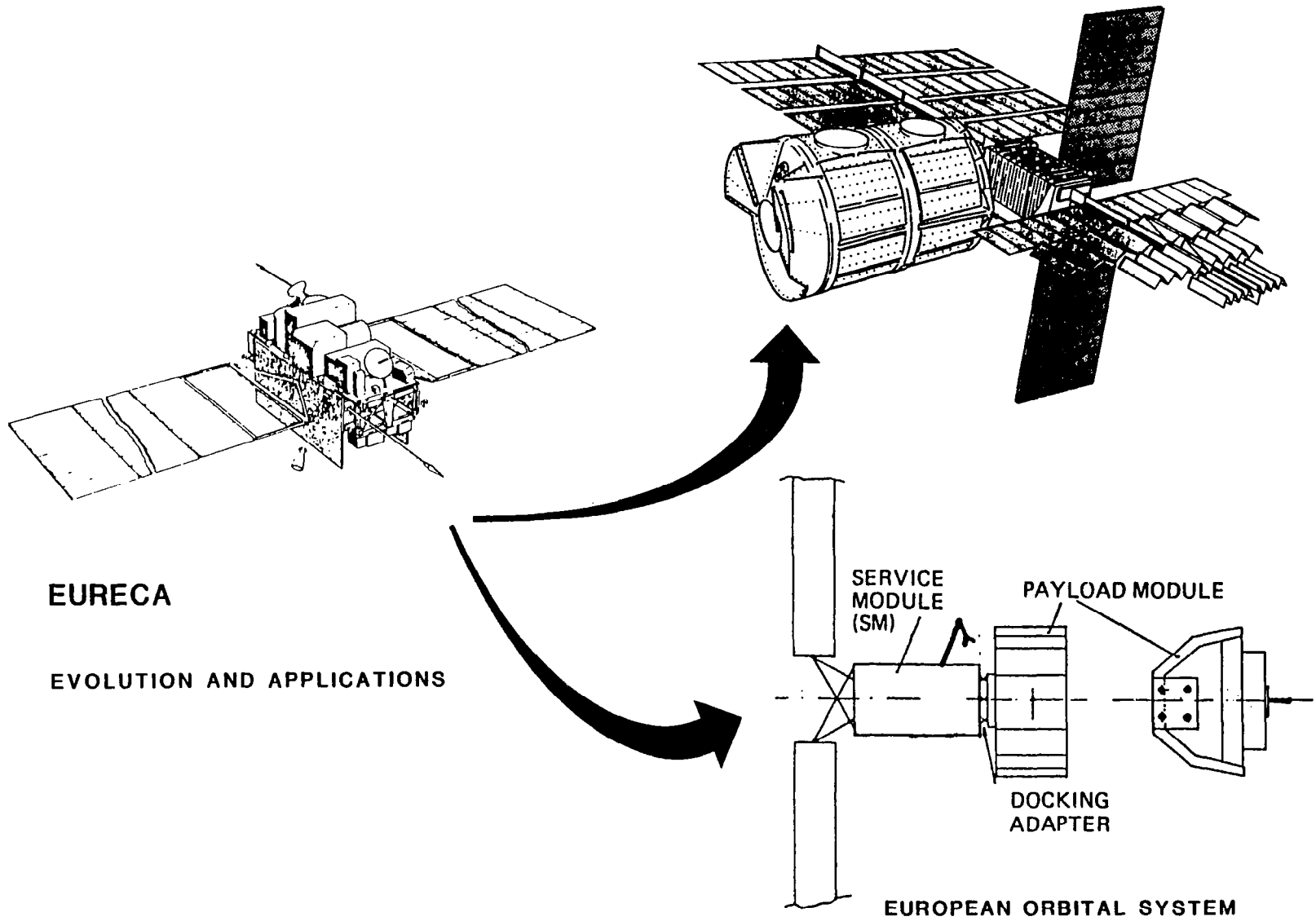
ESOC

-DEVELOPMENT OF GROUND SUPPORT FOR LEO WITH VERY LIMITED GROUND COVERAGE AND DEMONSTRATION OF INTERORBIT COMMUNICATION TECHNOLOGY (L-SAT)



Fig. 14

FREE FLYING EXPERIMENTAL MODULE



# CONESTOGA II A LOW COST COMMERCIAL SPACE TRANSPORT SYSTEM

by

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## ABSTRACT

Conestoga II is currently under development. It will be capable of inserting 500 Kg satellites into 800 Km circular polar orbits. Conestoga II makes maximum use of existing (developed) technology and hardware. Its commercial objective is to fill a need for low cost low earth orbital transport not efficiently served by Shuttle or larger space transport systems. The paper will expand on low earth orbit markets, foreign participation, and launch site considerations. Technical and economic trade-offs will be examined.

## INTRODUCTION

The Conestoga II, when completed, may very well be the world's first all commercial orbital transport vehicle. It is designed to be capable of inserting a 500kg (1100 lbs) satellite into an 815 Km (440 nm) circular polar orbit. The Conestoga II vehicle, as currently configured, is shown in Figure 1. Conestoga II will have over 3 times the orbital weight capability of Scout.

The value of Conestoga II rests on the premise that as the world continues into the space age, there will be an ever increasing need for efficient, low cost orbiting transport systems. The Conestoga II will serve a different market than the Shuttle and Ariane. The Shuttle and Ariane market involves very heavy payloads, many going into geostationary orbits. In an attempt to concentrate on the Shuttle, U.S. policy has been to abandon most of its dedicated expendable launch vehicles.

The Soviet Union, France (as part of ESA), Japan, China, and India all currently have national space programs with orbital vehicle capability. These Government programs may or may not constitute real competition in a commercial sense. The competition will depend on the degree of subsidizing which those countries offer to space transport users. It is our contention that the efficiencies inherent in a commercially directed program will provide Low Earth Orbital transport so low in cost that subsidized competition cannot long prevail.

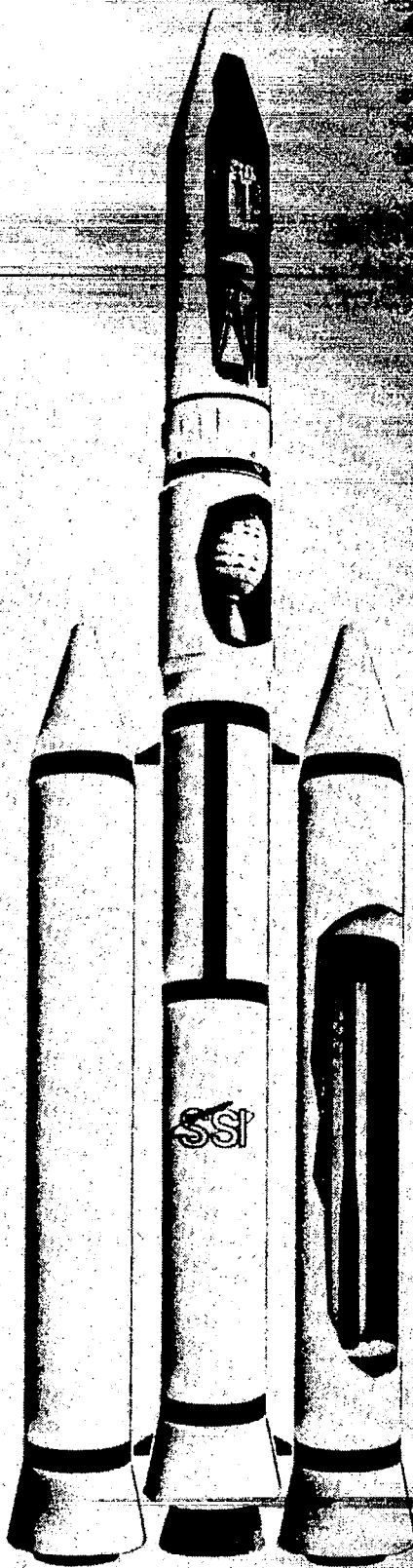
The technology for producing reliable, dedicated Low Earth Orbiting rocket vehicles is mature. That is to say, no breakthroughs are required. It remains only to select existing technology and hardware and to combine them efficiently.

Peaceful uses of low earth space include, but are certainly not limited to:

1. Data Collection and Communications Systems for Remote Sites. Applications include monitoring unattended oil wells, pipelines, and electrical power systems, water resources, communications with isolated outposts, and electronic mail.
2. Vehicle Location, Search and Rescue. Through the use of satellite Doppler data, trucks, ships, boats, railroad cars or any mobile vehicle can be position-monitored from space with location reporting several times per day. The ability of satellites to find downed aircraft and distressed ships at sea has already been proven.
3. Earth Resource Monitoring. Low Earth orbiting satellites similar to the U.S. Landsat systems can monitor renewable and non-renewable earth resources. These include oil field and mineral site surveying, agricultural monitoring for crop disease or drought, and for irrigation control.
4. Border Security Monitoring and Law Enforcement. Low Earth satellites with sufficient resolution can determine border infringement and illegal offshore operations.
5. Space Processing. The ability to process special medicines and to create new alloys in zero "G" environments is in its infancy. Space processing may ultimately dominate all other aspects in commercial importance.
6. Navigation and Surveying. The Transit satellites and now the Global Positioning System (GPS) satellites have revolutionized navigation. Interferometric systems using space technology offer the potential of establishing even greater accuracy with position fixes to within better than a meter.

Space transport technology involves a multiplicity of technical disciplines. They include: (1) rocket propulsion, (2) aerodynamics, (3) guidance, (4) control, (5) communications, (6) digital data processing, and (7) tracking. Reliable hardware and software is available in all of these disciplines.

The Conestoga II program will combine these existing elements to produce an efficient and low cost orbital launch system.



**CONESTOGA II**

**FIGURE 1**

## BACKGROUND

In January 1982, Space Vector Corporation (SVC) received a contract from Space Services, Inc. of America (SSI) to design, fabricate, and launch the first commercially sponsored suborbital rocket vehicle. This vehicle, designated Conestoga I, is shown in Figures 2 through 4. The principle mission of the Conestoga I was to demonstrate procedures and systems required for a full-up orbital space launch and establish a precedence for commercial ventures into space.

Conestoga I was successfully launched into space from Matagorda Island, Texas, September 9, 1982. The flight was a simulation of an orbital insertion sequence and successfully demonstrated booster guidance and control, payload separation, shroud separation, attitude control maneuvering, payload and 4<sup>th</sup> stage motor spin-up, and orbital insertion motor ignition. The payload followed a ballistic trajectory (see Figure 5), reaching a maximum altitude of 309 Km (192 statute miles). It re-entered the atmosphere and splashed down in the Gulf of Mexico 516 Km (321.5 statute miles) south of the Matagorda launch site.

The vehicle and launch facilities constructed at Matagorda to accommodate the Conestoga I launch were designed and put in place in less than 9 months. Radar tracking for flight safety and a telemetry receiving station were provided by subcontracting the services of DFVLR's Mobile Rocket Group. No U.S. Government facilities were used.

The successful launch operations of the Conestoga I program, covered extensively by U.S. and World news services, proved to be a milestone in the commercialization of space.

## CONESTOGA II

The Conestoga II orbital launch vehicle, now under development, is a four stage booster that will maintain this new impetus and provide the world with a low cost, multi-purpose, space launch system. The Conestoga II, as shown in Figure 6 is a four stage rocket using solid propellant motors. It has been configured to orbit second generation payloads in the 200 to 800 Kg class, and thus fill a void created by current government programs dedicated to Shuttle and Ariane class boosters.

The key elements in the evolution of the Conestoga II booster are:

- The development of the first and second stage booster rocket motors which are modified Castor IV motors produced by the Morton-Thiokol Corporation.
- The integration of the Castor motors with current U.S. technology flexible, vectorable nozzles (flex nozzles) and controlling them in a manner identical to Conestoga I.
- Controlling the 3<sup>rd</sup> and 4<sup>th</sup> stage motors by spin precession control using proven SVC control techniques demonstrated as on Conestoga I.

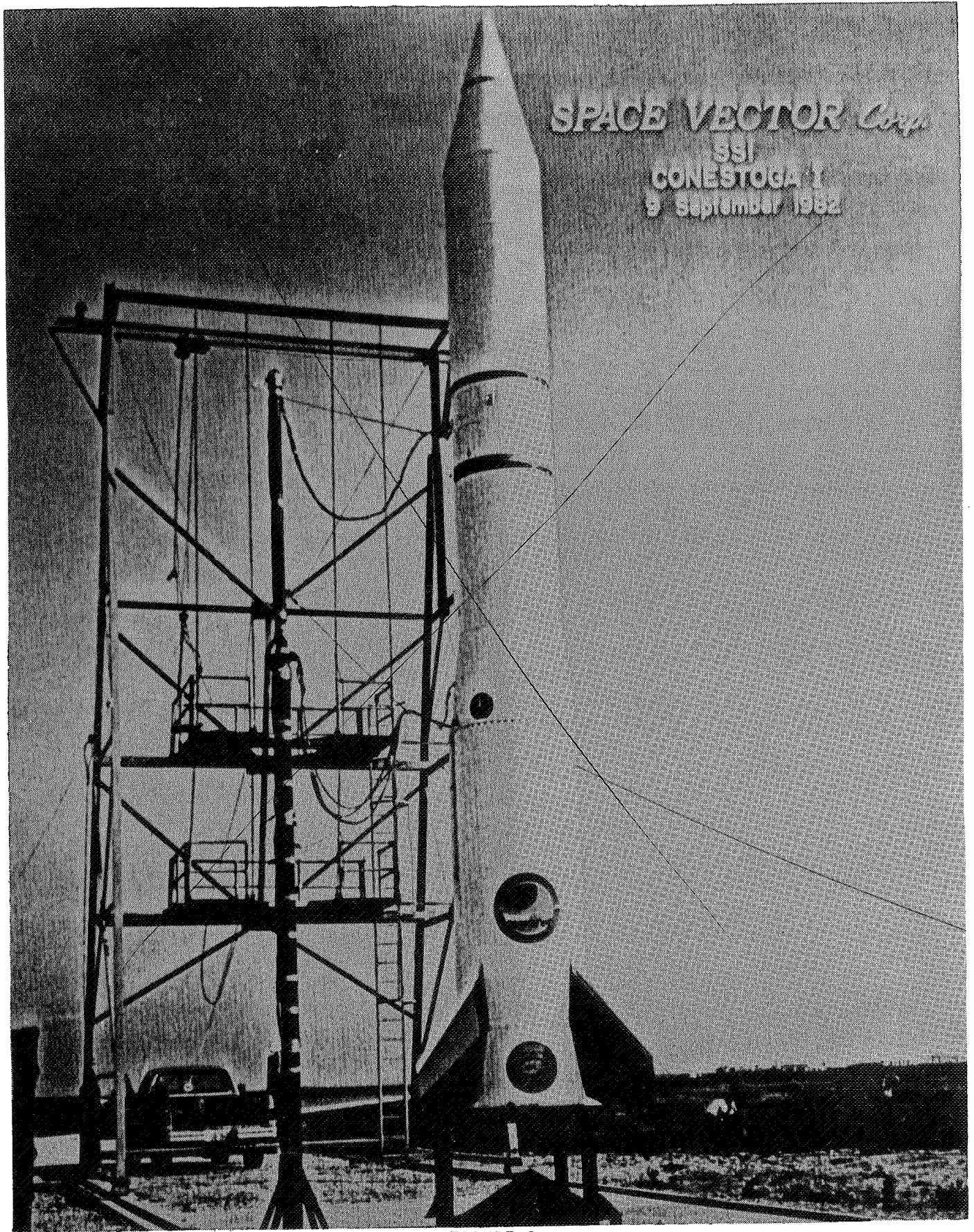
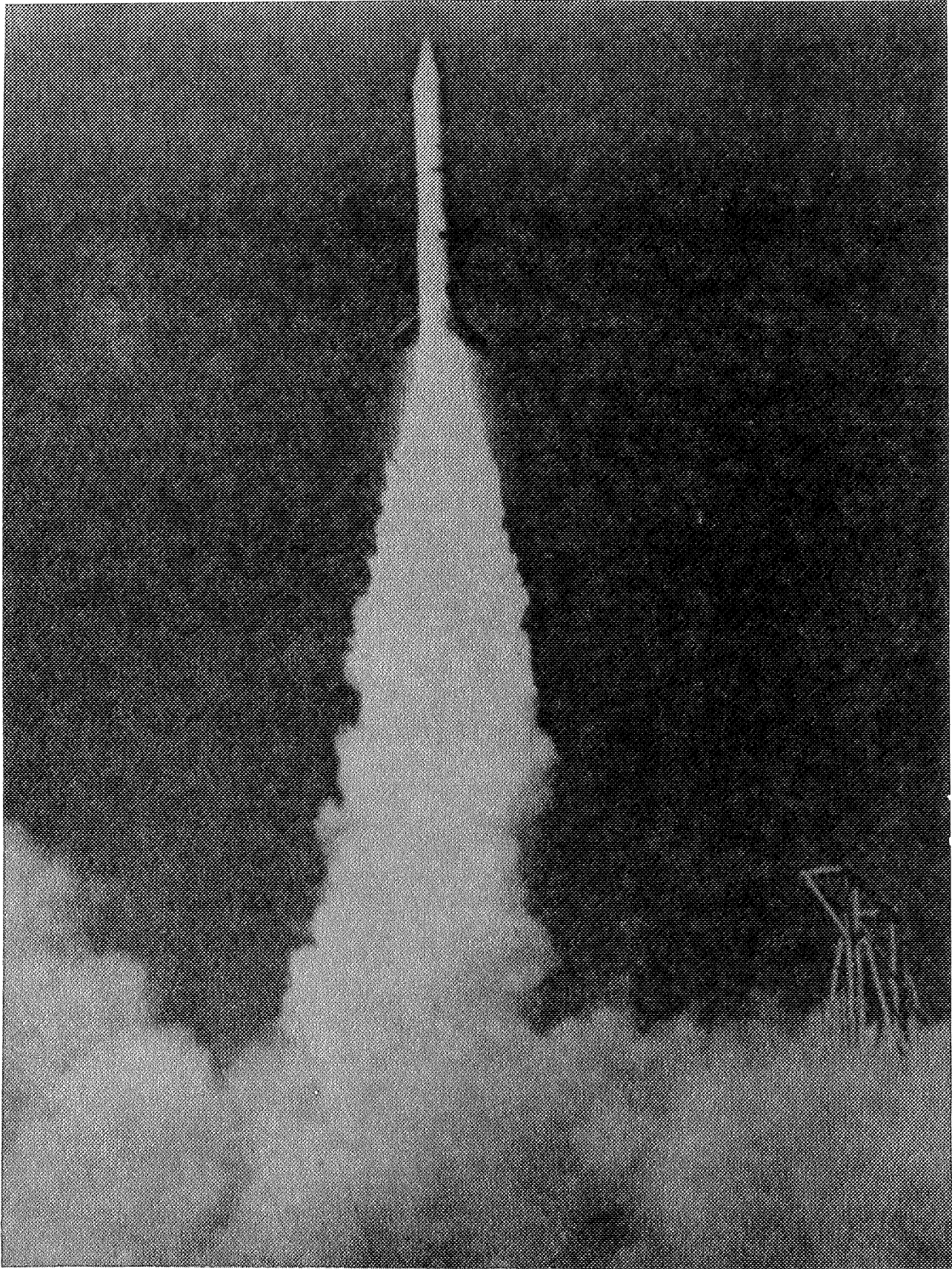
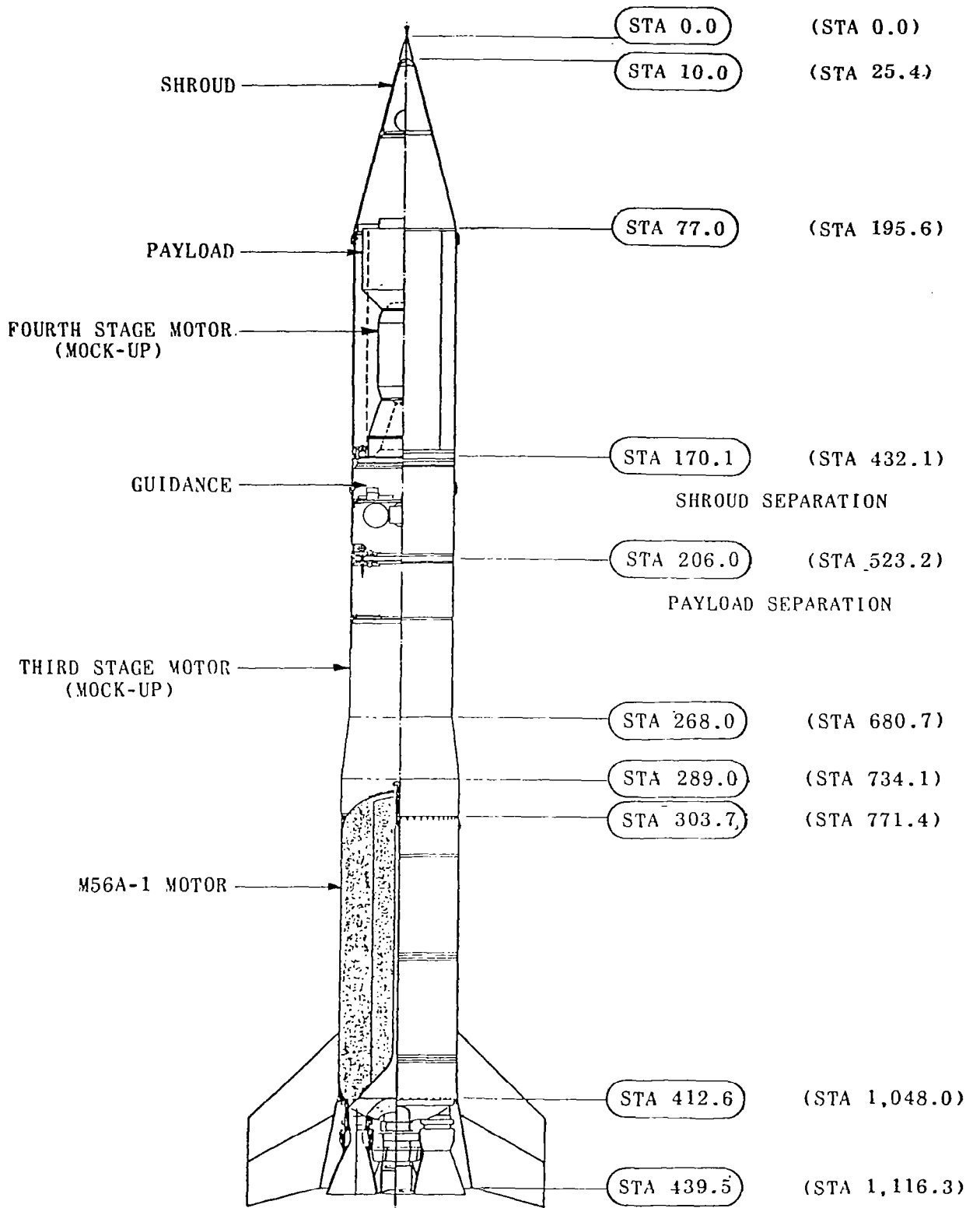


FIGURE 2



CONESTOGA I at Liftoff

FIGURE 3



CONESTOGA I

FIGURE 4

STATION #'S IN PARENTHESES ARE IN CM



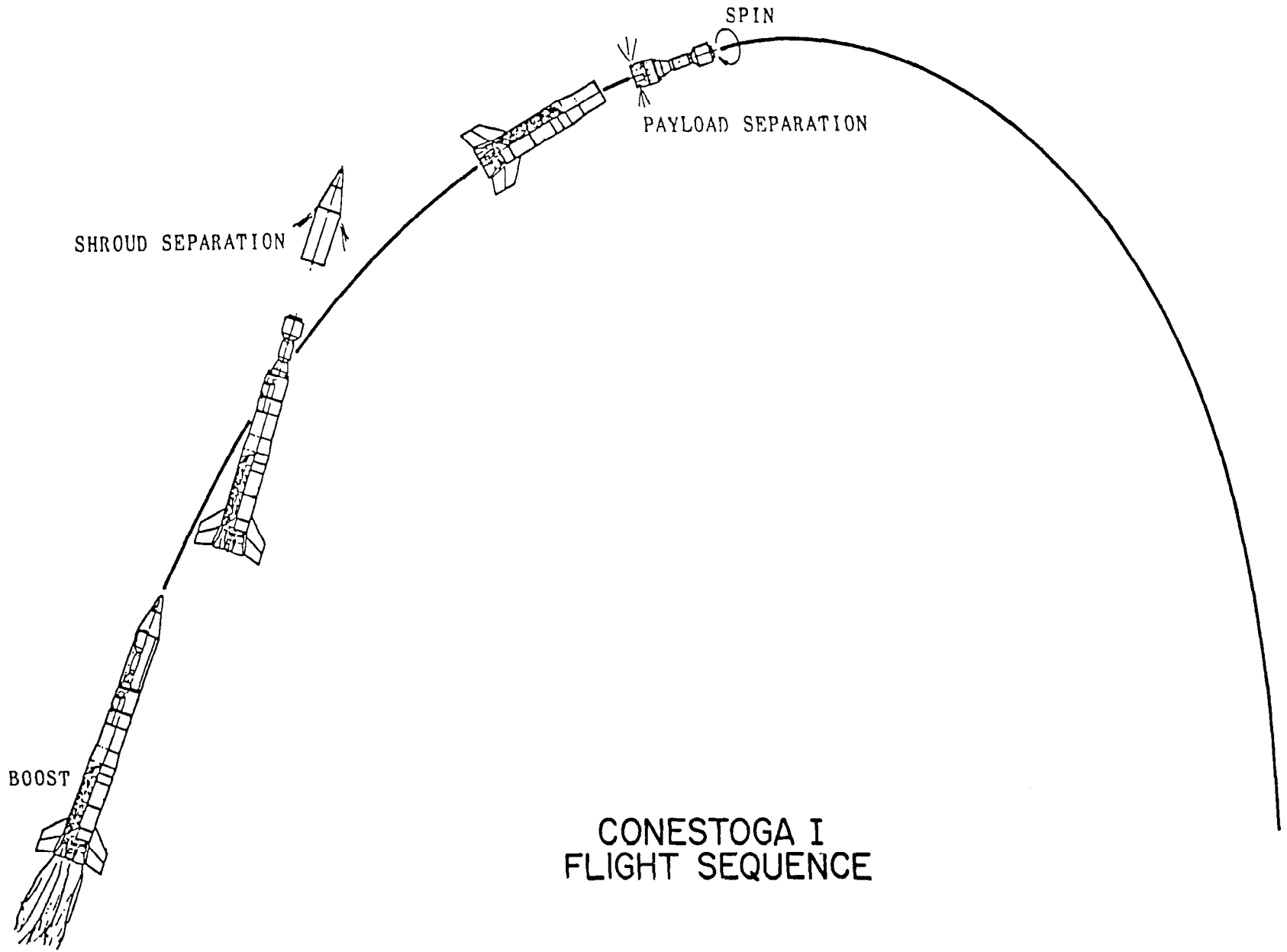


FIGURE 5

- Providing precision boost guidance with an inertial guidance system currently under development and being tested at SVC. Modern computer technology has made this approach commercially available to all users.

The program is currently concentrating on:

- Castor IV modification and test.
- Integration of the flex-nozzle to the Castor IV.
- Preliminary design and specifications for the hydraulic nozzle control unit.
- Testing of the SVC advanced inertial guidance unit.
- Systems design and integration.

To assure reliability and reduce development and launch costs, the vehicle is based on proven hardware and technology available from past and existing programs.

Stage 1 is composed of two Castor 4H motors with fully vectorable nozzles (+6°) with 8:1 expansion ratios. These two motors are attached to either side of the central core Stage 2 motor. Following Stage 1 burnout, the two Stage 1 motors are separated from the remaining vehicle.

Stage 2 is also a Castor 4H motor with a vectorable nozzle. The nozzle has an expansion ratio of 11:1. After Stage 2 burnout, the expended motor case is released.

A Star 48 or equivalent class motor with a fixed nozzle has been chosen as the 3<sup>rd</sup> stage. Stage 3 ignition occurs above 400,000 ft. (123 km), i.e., above the sensible atmosphere. The third stage will be spin stabilized and guided by a cold gas system in the Guidance and Control Module.

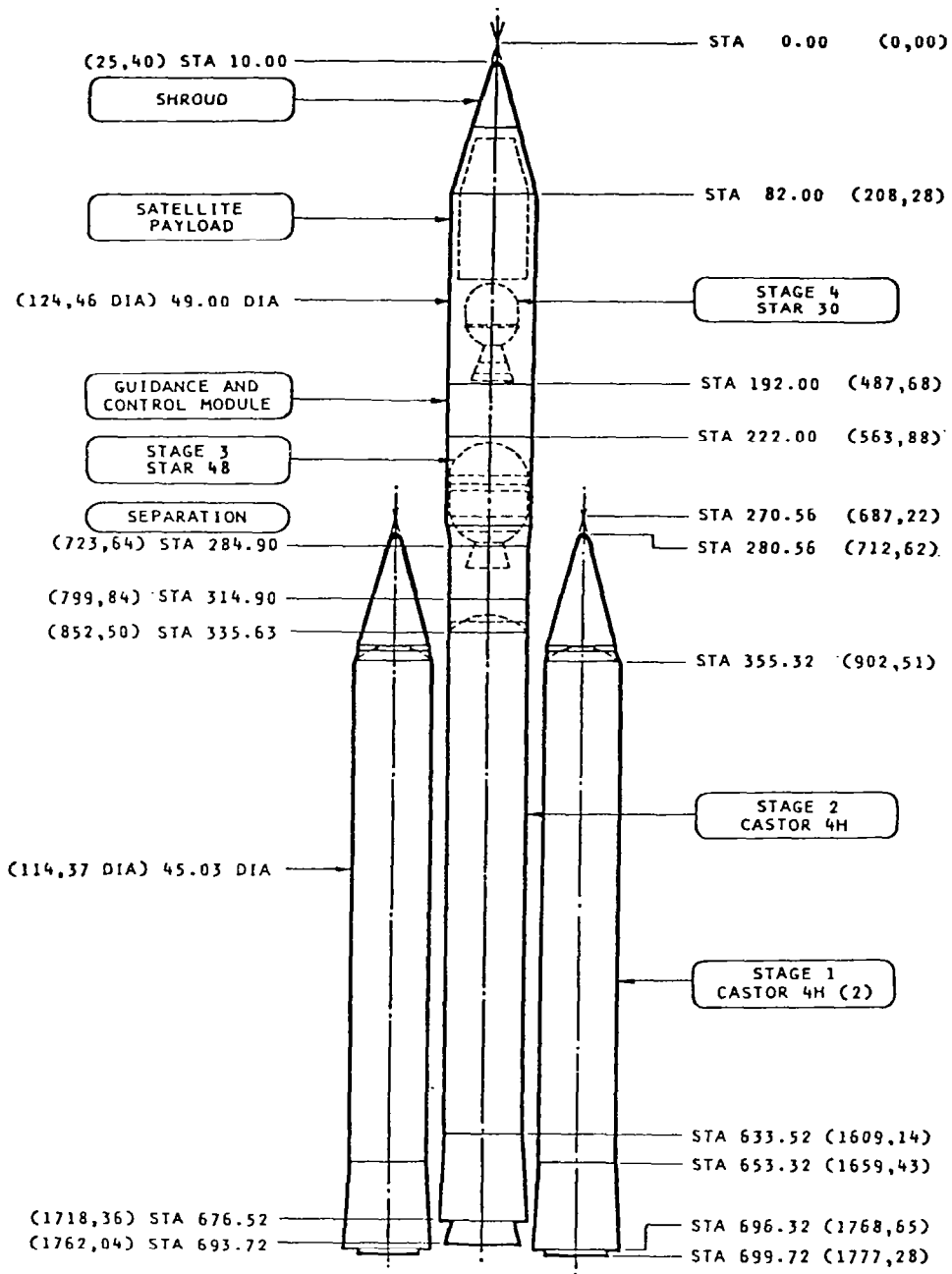
The choice of the Stage 4 orbital injection motor will depend on the size of the payload and any special acceleration limits it may have. On the baseline Conestoga II configuration, a Star 30 motor is depicted.

The Guidance and Control Module, located between Stage 3 and Stage 4, contains the inertial guidance platform, computer electronics, telemetry, and the cold-gas Attitude Control System (ACS).

Enclosed over the payload and Stage 4 motor is a clam-shell split shroud which is separated and released when the vehicle has ascended above the atmosphere. A variety of shroud lengths and diameters can be accommodated.

A weight summary is presented in Table 1.

The four stage Conestoga II is a flexible launch system capable of placing a variety of satellite payloads into near earth orbits. It can place satellites into a full spectrum of orbital inclinations, from pure easterly to polar and retrograde planes.



DIMENSIONS IN PARENTHESES  
 ARE IN CENTIMETERS

### CONESTOGA II

FIGURE 6

The estimated performance of the baseline Conestoga II for easterly and polar orbits is shown in Figure 7.

Preliminary error analysis of the Conestoga II inertial guidance system indicates that orbital insertion accuracies of  $\pm 15$  Km in apogee/perigee and  $\pm 0.5^\circ$  inclination error are possible without ground updating.

The Conestoga II can place upper stage velocity packages into low Earth parking orbits for boost out to geosynchronous transfer and other elliptical orbits. The Conestoga II can place 274 Kg (600 lbs) into geosynchronous transfer orbit and, with the proper apogee motor, a 137 Kg (300 lbs) satellite could be stabilized in geosynchronous orbit. Similar sized payloads could be launched on interplanetary trajectories.

Figure 8 shows the Conestoga II mission profile. Figure 9 shows the vehicle after 3<sup>rd</sup> stage separation undergoing spin up. Both 3<sup>rd</sup> and 4<sup>th</sup> stages will be attitude oriented prior to firing using the ACS system under the control of Conestoga's inertial guidance system.

Figure 10 shows nominal acceleration profiles of 1<sup>st</sup>, 2<sup>nd</sup>, and 3<sup>rd</sup> stages. The 4<sup>th</sup> stage acceleration, being motor and payload weight dependent, is shown with a number of choices in Figure 11.

Figure 12 shows altitude and dynamic pressure as a function of time.

The system inertial guidance utilizes the Space Vector Corporation RIMS II inertial guidance platform originally built and qualified for Sandia National Laboratories. Figures 13 and 14 show this unique roll stabilized inertial guidance platform. Its ability to withstand high spin rates and accelerations is the key to the ability to use inertial guidance during operation of the spinning 3<sup>rd</sup> and 4<sup>th</sup> stages.

A payload shroud is provided to protect the payload during ascent. The shroud will be jettisoned during second stage burn after the vehicle has risen above the atmosphere. Aerodynamic loads and heating inputs are carried through the shroud to the forward face of the Guidance and Control Module. The shroud design is a standard cone-cylinder configuration and will be fabricated in two half shells constructed of a composite material structure utilizing an inner honeycomb sandwich. A stainless steel nose tip will protect the shroud at the point of maximum heating.

A variety of payload sizes can be accommodated. The standard shroud size is 462 centimeters (182 inches) long and 124 centimeters (49 inches) in diameter. This shroud allows a payload volume of 0.84 cu. m. (30 cu. ft.) if a Star 30 motor is used as stage four.

Concerning satellite separation, there will be only a simple mechanical interface between the satellite and the booster. The mechanical interface will be a standardized adapter to permit a single-point-release, attach/deployment mechanism. The adapter/deployment mechanism will be capable of imparting a 1.53 meter per second (5 foot per second) separation velocity between the payload and final stage.

The satellite will be electrically self-contained with no electrical inter-connection between the satellite and the launcher.

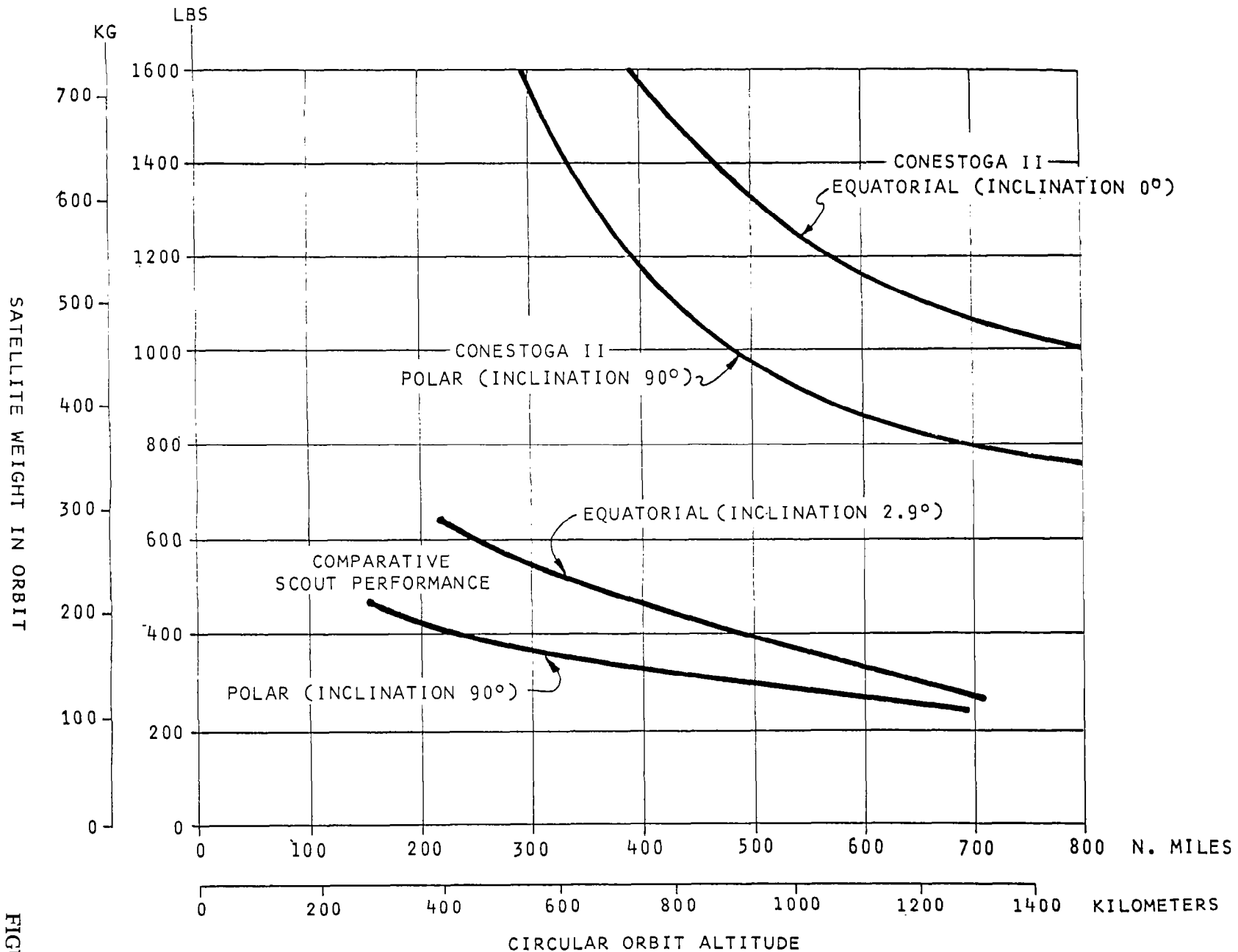
## CONESTOGA II

### Vehicle Weight Summary

	Weight, lbs.	Kgs
Satellite	800	363.6
Shroud*	300	136.3
Satellite Separation System	22	10.0
Stage 4 Inert Motor (Star 30)	57	25.9
Stage 4 Propellant (Star 30)	1027	466.8
Guidance and Control Module	445	202.3
Stage 4 Separation System	20	9.1
<u>Stage 3</u>		
Separation System	20	9.1
Inert motor (Star 48)	235	106.8
Propellant (Star 48)	4425	2011.3
Structure	102	46.3
ACS Nozzles	20	9.1
Spin Rockets	5	106.8
<u>Stage 2 (Castor 4H)</u>		
Inert motor	2997	1362.2
Propellant	28029	12740.4
Hydraulic System	46	20.9
Attachment Fittings - Separation System	60	27.3
Aft Skirt	160	72.7
Stage 3 adaptor	140	63.6
<u>Stage 1 ( 2 Castor 4H)</u>		
Inert Motors (2)	5734	2606.3
Propellant	56058	25480.9
Aft Skirts (2)	320	145.4
Motor Nose Cones (2)	240	109.0
Attachment Structure	320	145.4
Hydraulic System (2)	92	41.8
Total Lift-off Weight	101,674	46,215.44

\*Jetisoned during Stage 2 burn

Table 1



CONESTOGA II PERFORMANCE TO LOW EARTH ORBIT

FIGURE 7

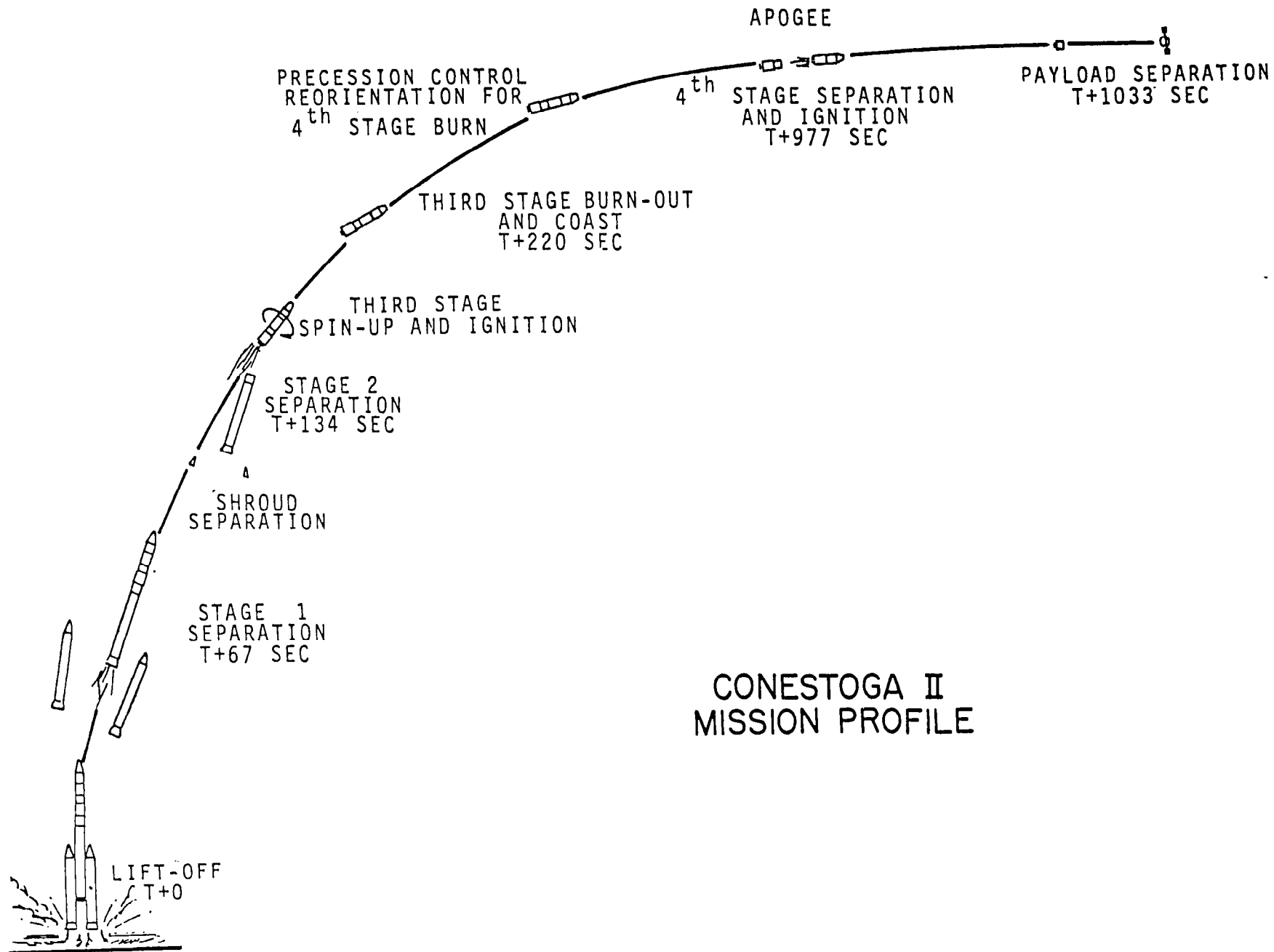
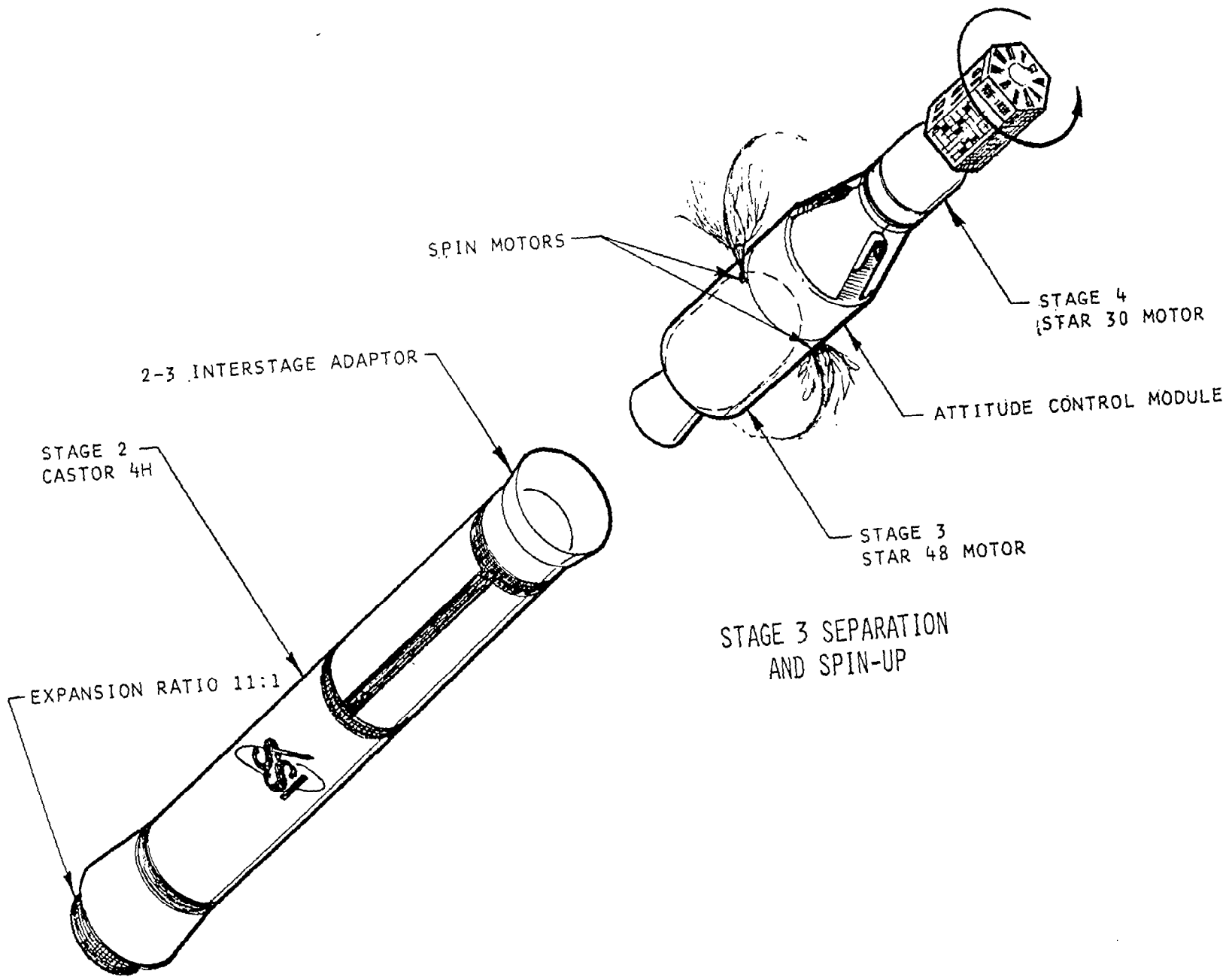


FIGURE 8





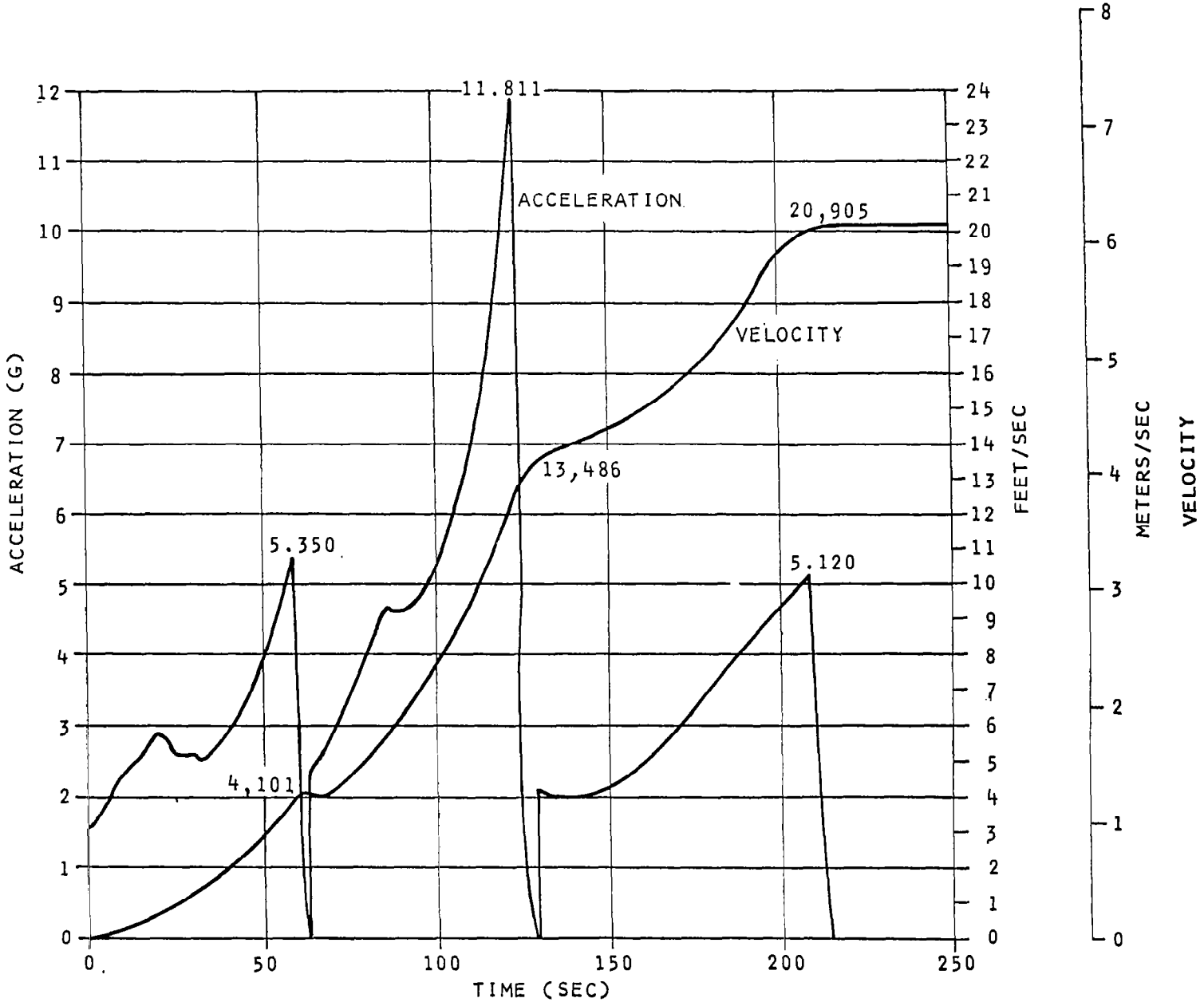


FIGURE 10

CONESTOGA II  
VELOCITY AND ACCELERATION HISTORY

MAXIMUM G LEVEL vs SATELLITE WEIGHT  
FOR VARIOUS STAGE 4 MOTORS  
DURING STAGE 4 THRUSTING

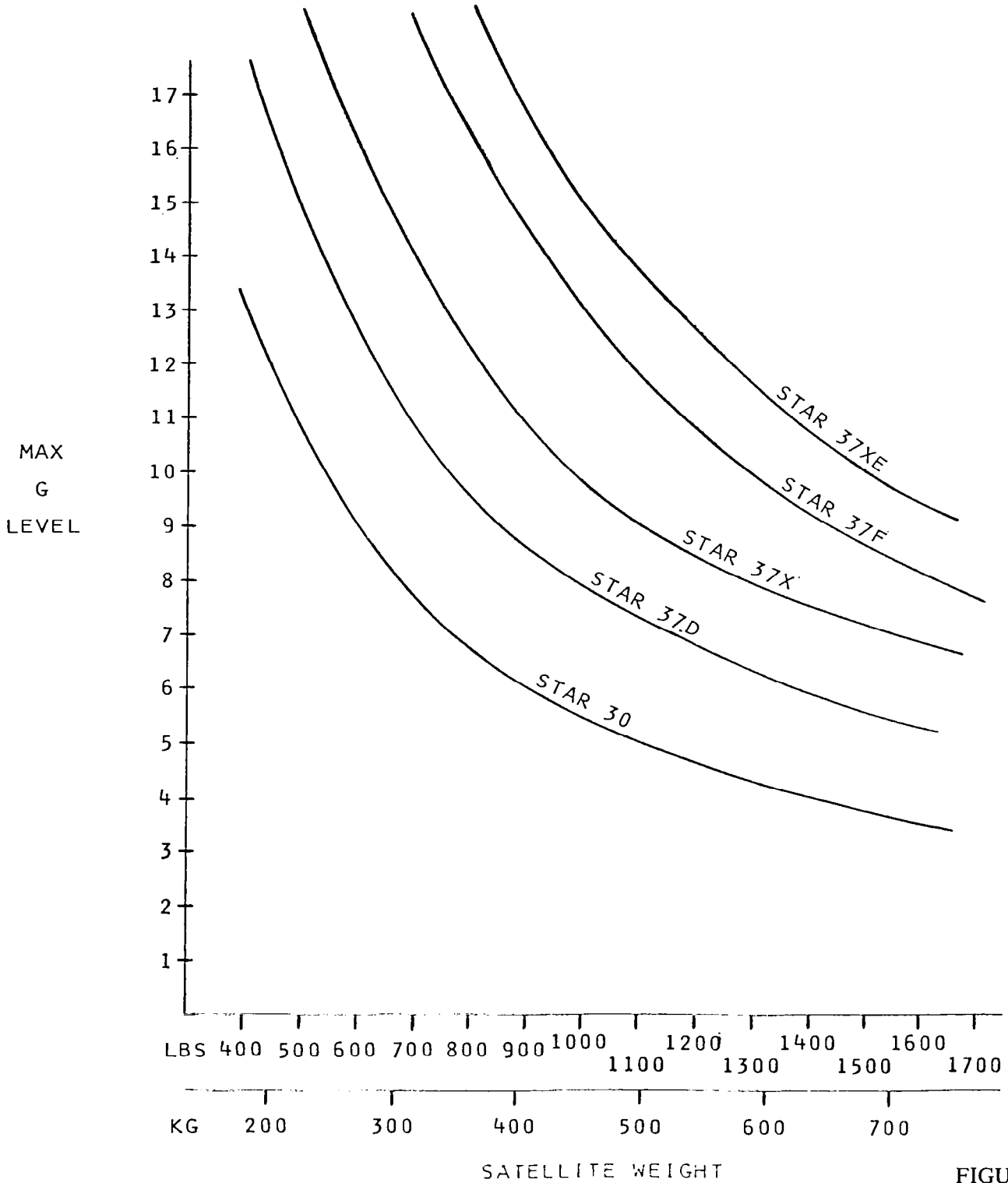
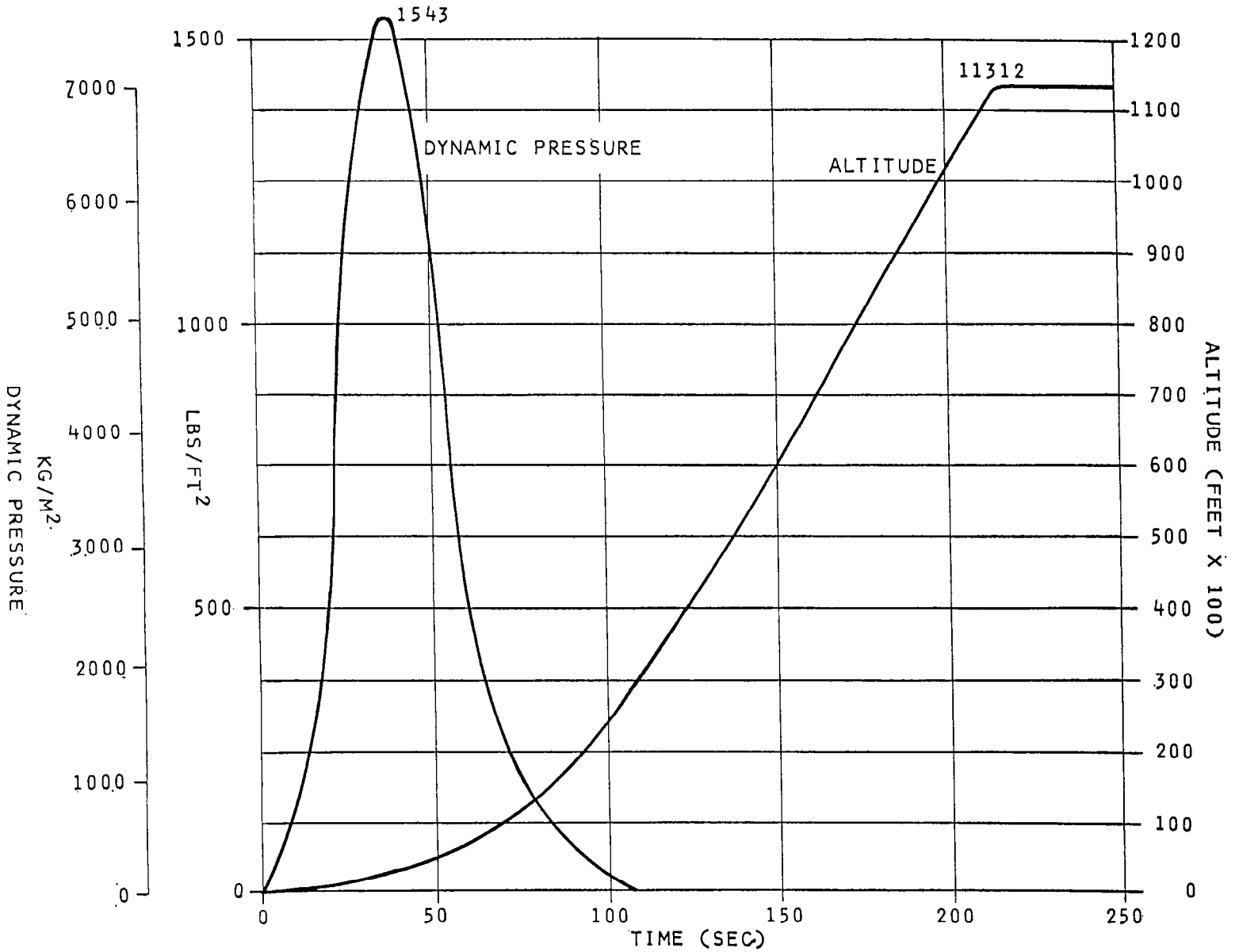
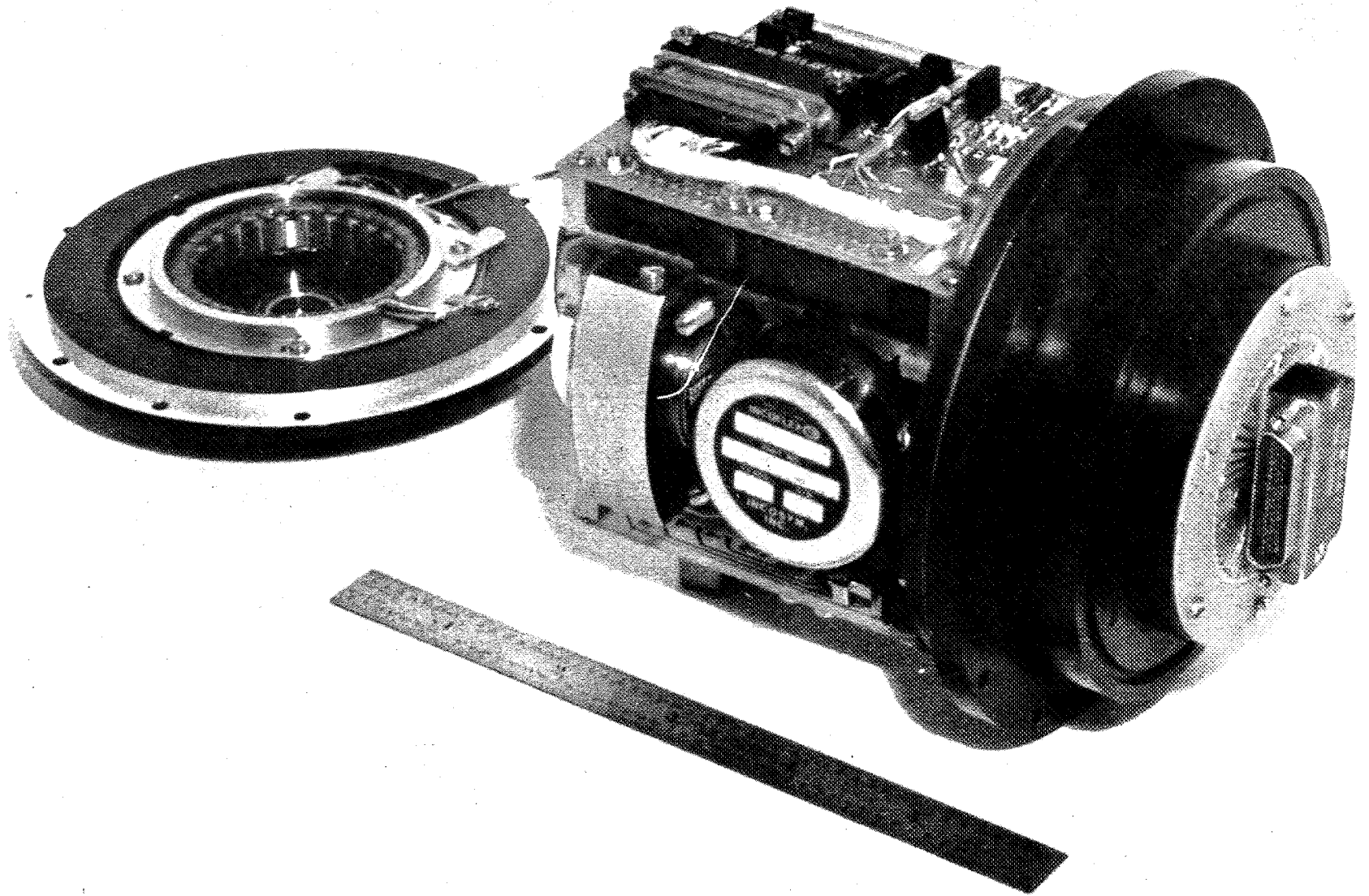


FIGURE 11



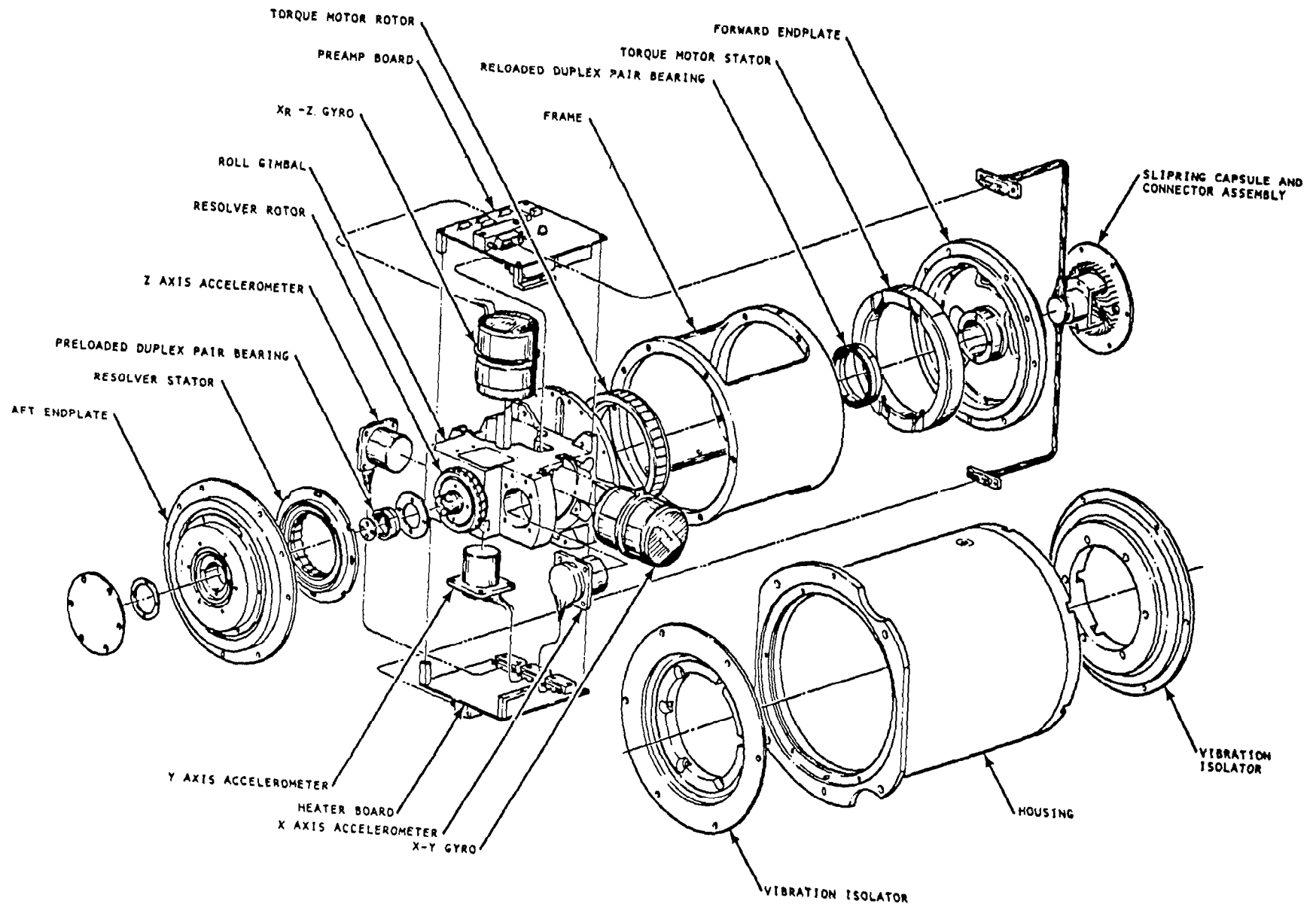
CONESTOGA II  
ALTITUDE AND DYNAMIC PRESSURE

FIGURE 12



THE RIMS II ROLL-STABLE INERTIAL PLATFORM

FIGURE 13



PLATFORM ASSEMBLY, RIMS 11A

FIGURE 14

## LOGISTICS AND LAUNCH OPERATIONS

The Conestoga vehicle has been designed for practical logistic support and mobile operations.

Minimum time is required to assemble and launch the rocket since all systems are pre-tested prior to shipping.

For support purposes, the motors and payload sections can be shipped in standard 40 ft. (12.19 meters) cargo shipping containers. The Castor IV H motors each require a container with the fourth container holding the upper stages, the control module, and the payload.

The launch gantry will either be built as a kit and shipped by container to the launch site or will be built from local materials.

The launch control center can be built into a container module, tested with the vehicle and shipped anywhere in the world.

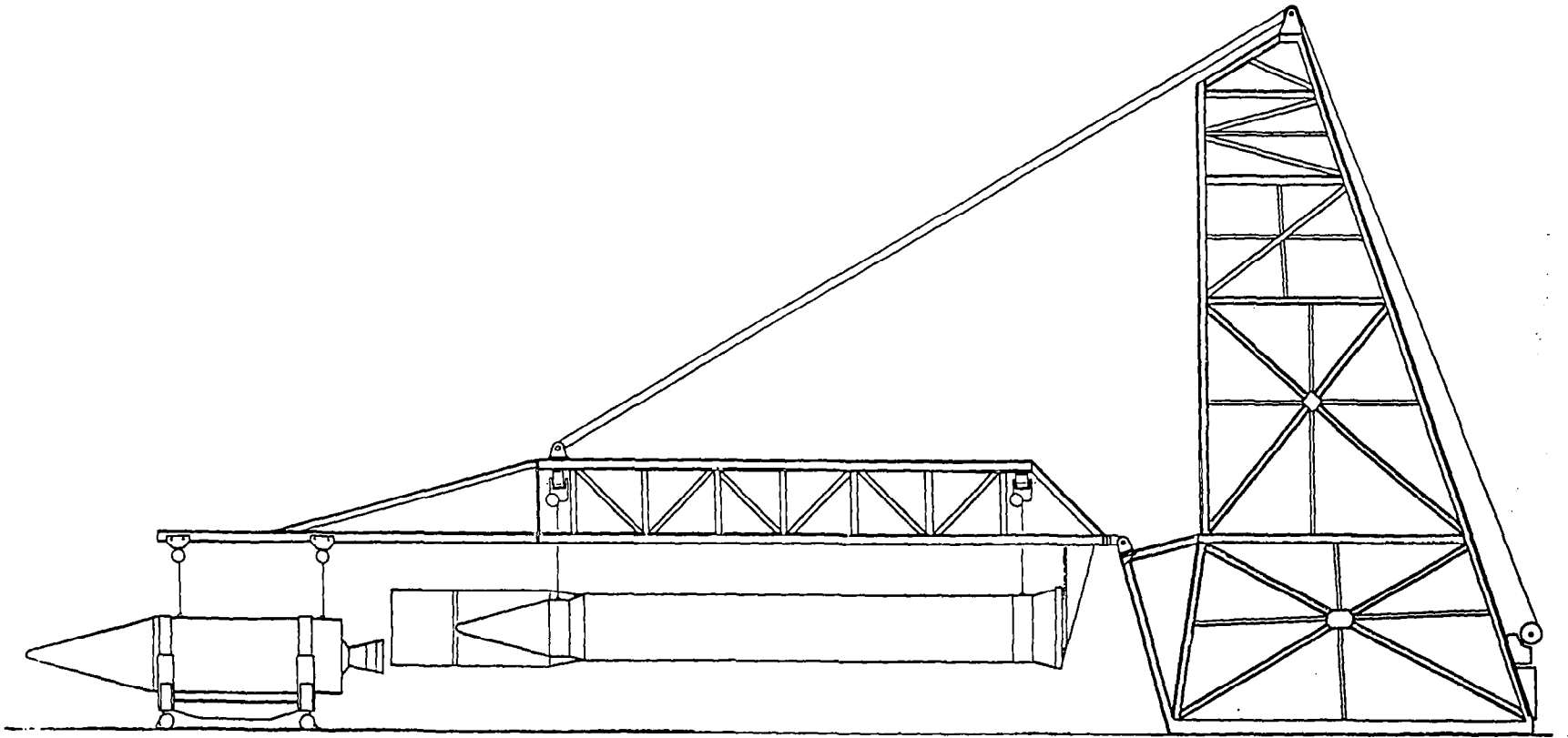
Launch operations include vehicle integration on the pad, prelaunch tests of all launch vehicle, systems, launch, telemetry, tracking, and range safety.

The facilities required to launch the Conestoga II include:

1. Launch pad and roll away gantry
2. Vehicle Assembly Building (VAB)
3. Payload preparation and inspection facility (depending on payload)
4. Launch Control Block house
5. Facility Cable Plant
6. Tracking Radar
7. Telemetry
8. Thrust Termination System Transmitter
9. Required facilities for on-site personel
10. Communications
11. Electrical power
12. Transporter-erector, crane, or hoist

The vehicle will be horizontally assembled and erected in the vertical position as shown in Figure 15.

Because of the vehicle's all solid rocket motor configuration, the launch facility requirements are considerably reduced as compared to those required for liquid propulsion systems. Depending on the launch site, launches can be conducted



CONESTOGA II  
HORIZONTAL ASSEMBLY

FIGURE 15

on a campaign basis with operations beginning two months prior to launch and requiring a launch crew of approximately 15 engineers and technicians. If the launch rate is sufficiently high, a permanent launch organization would be established.

### ECONOMIC CONSIDERATIONS

A key question as relates to Conestoga II is how to predict the satellite market. It is most difficult to "crystal ball" sales for any systems related to rapidly advancing technology. I suspect Henry Ford had similar difficulties in justifying sales projections for the Model T prior to its development. He may have erred on the low side.

The world demand for space launches is not likely to disappear. If space transport costs can be significantly reduced, volume will increase. An important factor in cost is the inherent efficiency of a commercial operation as opposed to government operations. Our analysis shows that after development of Conestoga II, we could be very competitive at profit margins up to 50%. We do not need many sales to recognize break-even and substantial earnings.

We have examined the space transport market from four points of view: 1) extrapolation from previous satellite launch density, 2) a survey of potential foreign users, 3) a summary of known or planned future programs including civil and military government and private utilization, and 4) an analysis of the market by payload type and satellite use. Two of these analyses are summarized in this paper.

Figure 16 shows the overall market projection based on an extrapolation from historical market data.

A ten year projection, Figures 17 and 18, is based upon analysis performed by consultants to SVC. This study tends to substantiate the low end of the projection, Figure 16, and provide some measure of probable time phasing. Our market effort has been directed primarily towards the near term (5 year projection) indicated on the Figure. These data are based primarily upon currently planned satellite missions. The U.S. commercial applications would appear to be a sustaining level of support. The project shows a dramatic increase in the subsequent five year period based upon the near certainty of South American and smaller nations' satellites in this time frame.

The USAF, paradoxically, could be a large user. This projection hinges on three conditions. The first is that the U.S. ballistic missile defense posture remains bullish, thus requiring a significant program of sensor and space weapons testing. The second condition is that through demonstration of performance during our commercial launches, we can sell the military on a turnkey service -- at a great savings in both cost and development time to the U.S. government. Preliminary indications are that at least the policy making level of government is receptive to this approach. The third condition, and the least constraining, is that due to the classified nature of military test launches, we must provide services at CONUS launch facilities.



### LOW EARTH ORBITER MARKET DATA

Total Annual Space Budget - USA*	\$ 7.5 billion
Total Annual Aerospace Budget - USA*	65.0 billion
Estimated Total Annual Space Budget - World	16.0 billion
Number of Satellite Launches - USA** Period of 1969 through 1981	347
Number of Satellite Launches - World** Period of 1970 through 1981	1,708
Number of Scout Launches** Period of 1961 through 1983	102
Estimate of Low Earth Orbit Satellites Period of 1983 through 1993 (excluding Soviet Union)	330
Estimated Conestoga II Share	30-60
Estimated Vehicle Operation Gross at \$8.0 Million/Launch (Less Range Costs)	<u>\$ 240-480 million</u>

\*Aviation Week, March 14, 1983.

\*\*TRW Space Log - 1982

FIGURE 16

A 10-YEAR PROJECTION FOR CONESTOGA II ORBITAL LAUNCHES

<u>User Country or Group</u>	<u>Low Earth Orbiter Satellites</u>	<u>Specifically Identified Near Term Planned Missions Which Could Use Conestoga II</u>
A	Location, search, & rescue	4
B	Earth resources	1
C	Data collection	2
D	Earth resources	1+
E	Uncommitted	0
U.S. NASA/ Air Force (CONUS Launch Facility)	Targets/navigation satellites	2
U.S. Commercial		4+

FIGURE 17

A 10-YEAR PROJECTION FOR CONESTOGA II ORBITAL LAUNCHES

<u>User Country or Group</u>	<u>Low Earth Orbiter Satellites</u>	<u>Years - Beginning 1984</u>		
		5	10	20
A	Location, search, & rescue	1	1	} Major market for multiple satellite applications.
B	Earth resources			
C	Data collection	1	1	
D	Earth resources	2	2	
E	Uncommitted	0	4	
U.S. NASA/ Air Force (CONUS Launch Facility)	Targets/navigation satellites	0	6	} Sustained defense testing.
U.S. Commercial		3	5	
Subtotal:		7	19	
<u>User</u>	<u>High Altitude/Geosynchronous</u>			
Foreign countries	Communication & geopolitical	1	3	} Expanding market. Dependent upon advanced technology.
U.S. Commercial	Advanced communications systems	0	2	
USAF (CONUS Launch Facility)	Space based defense testing	0	3	
Subtotal		1	8	
Total Projected Satellite Launches		8	27	

FIGURE 18

## SUMMARY

In summary, we feel that Conestoga II may very well be the Model "T" of space over the next decade. There is no reason that an excellent balance cannot be obtained between cost and reliability. Conestoga I has gone a long way toward proving the commercial space transport option. Conestoga II should make this option a reality.

# COMMENTS ON THE COMMERCIALIZATION OF EXPENDABLE LAUNCH VEHICLES

by

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## ABSTRACT

The President's national space policy encourages private sector investment and involvement in civil space activities. Last November, the President designated the Department of Transportation as lead agency for the commercialization of expendable launch vehicles. This presents a substantial challenge to the United States Government, since the guidelines and requirements that are set now will have great influence on whether American firms can become a viable competitive industry in the world launch market. There is a dual need to protect public safety and free the private sector launch industry from needless regulatory barriers so that it can grow and prosper.

## BACKGROUND

In recent months, there has been considerable public attention focused on commercialization of expendable launch vehicles (ELVs). Actions taken by the President have made it clear that as a nation, we will encourage the emergence and development of a viable private sector launch business. There is a long history of public policy that supports the move to commercially-owned and operated expendable launch vehicles. NASA and DOD have been active in the area of space transportation for twenty-five years; it has been a national policy for almost half that time that private sector space endeavors are to be encouraged by making available government-operated space transportation on a reimbursable basis.

There now appears to be a number of opportunities for commercial space ventures that can be fully managed and operated by the private sector. Most of these are derived from work sponsored by NASA, which has spawned these developments by encouraging and conducting scientific and high technology experiments, and making their findings readily available for spin-off into commercial ventures. This reflects long standing patterns of government-sponsored research and development and subsequent private sector commercialization in many fields. In turn, technological innovation and productivity improvements have led to increased economic growth and a higher standard of living for our country.

Many justifications have been suggested for why the nation needs a commercial expendable launch vehicle industry.

- An ongoing, efficient, private sector ELV industry will provide a versatile national launch capability at little or no cost to the Government.
- An expendable launch vehicle industry is needed to ensure the United States leadership position in this high technology, rapidly changing market, by maintaining our ability to compete directly with Ariane as well as the Russian and Japanese expendable launch vehicle offerings.
- Expendable launch vehicles can be dedicated to a single mission, placing the payload desired into the particular orbit desired at the precise time desired.
- For many applications expendable vehicles are inherently the most economical way to launch. They don't require the safety features of manned flight nor is there an opportunity cost for the time of payload integration.
- Competition provided by an ongoing, efficient private ELV industry could foster new technological developments in space transportation. It has been the government's experience that competition inevitably spawns innovation, creativity and efficiency.
- Some proposed enterprises may prefer to go into partnership with a private firm rather than the United States government to mount their space oriented activities.

On May 16, 1983, President Reagan issued his policy on Commercialization of Expendable Launch Vehicles. <sup>1/</sup> This statement further enlarged his National Space Policy which encourages private sector investment and involvement in civil space activities. It states that our government will encourage and facilitate commercialization of an American expendable launch vehicle industry.

The policy indicates that it is in the national interest to commit this country to a two-fold approach to space transportation: a government-owned and operated Shuttle, and a privately-owned and operated ELV capability.

On November 16, the President designated the Department of Transportation as the lead agency for commercializing expendable launch vehicles. In his State of the Union address on January 25, 1984 <sup>2/</sup> he noted that:

"The market for space transportation could surpass our capacity to develop it. Companies interested in putting payloads into space must have ready access to private-sector launch services."

"The Department of Transportation will help an expendable launch services industry to get off the ground. We will soon implement a number of executive initiatives, develop proposals

to ease regulatory constraints and, with NASA's help, promote private sector investment in space."

Three days later, in his Saturday radio address of January 28, 3/ the President reaffirmed his commitment to encouraging American industry to move quickly and decisively into space. He said,

"Obstacles to private sector space activities will be removed, and we'll take appropriate steps to spur private enterprise in space.

"We expect space-related investments to grow quickly in future years creating many new jobs and greater prosperity for all Americans. Companies interested in putting payloads into space, for example, should have ready access to private sector launch services.

He directed Transportation Secretary Dole, to

"work to stimulate the private sector investment in commercial, unmanned space boosters. We need a thriving, commercial launch industry. NASA, along with other departments and agencies, will be taking a number of initiatives to promote private sector investment to ensure our lead over current and potential foreign competitors. So, we're going to bring into play America's greatest asset: the vitality of our free enterprise system."

An Executive Order will soon be issued to implement this policy. It will draw heavily on the recommendations of the National Security Council's interagency working group on commercialization of expendable launch vehicles. These include authorization for the Department of Transportation:

- to act as a focal point for expendable launch vehicles contacts with the federal government;
- to promote and encourage expendable launch vehicle operations;
- to lead other agencies in expediting their licensing of launches and ranges;
- to identify federal statutes, treaties, regulations, and policies that may adversely affect expendable launch vehicle commercialization and should be changed; and
- to conduct appropriate planning concerning federal activities related to expendable launch vehicle commercialization.

The working group also recommended that all involved agencies review and revise their regulations and procedures, to eliminate unnecessary regulatory obstacles to the development of commercial expendable launch vehicle operations, and to ensure that essential regulatory procedures and requirements are administered as efficiently as possible.

Thus, the Department of Transportation has assumed the role of "new kid on the block" in the space business and has been asked to share with this symposium some observations on commercialization of expendable launch vehicles.

To any observer, the dynamics and the accomplishments of the space business are astounding. The practicalities of developing a viable commercial expendable launch vehicle business, however, are obviously more complicated. Our corporate world has long demonstrated that it is capable of making business decisions that involve extraordinary technical complexities and high financial stakes. This is pioneering in every sense of the word. In order to proceed, they must know what government will do when they are ploughing new ground. It will be the Department of Transportation's role to make sure that the government gets out of the way of the economic development of this industry, that we make the licensing process as simple as it can be, and that we encourage and facilitate the industry.

### REGULATORY THICKET

Perhaps the most immediate problem confronting the industry is what Secretary Dole has described as the thicket of regulations and clearances. <sup>4/</sup> The present federal licensing process is disorganized, expensive and time consuming. Many regulations that affect space launches came about for purposes unrelated to the development and operation of ELVs.

There has been relatively little experience with licensing privately-owned and commercially-operated space launches in the United States. Recently however, we have had two instances of private sector firms having worked their way through the variety of government reviews and requirements imposed -- Space Services, Inc. and Starstruck Inc. Prior to their entry on the scene, most launches had been government sponsored, and licensing was not an issue. Their experiences have been amply detailed in several public documents <sup>6/</sup> and will just be summarized here as reconstructed by the DOT staff, to be illustrative of how difficult the process can be. It should be noted from the start that these two small and innovative companies chose to challenge the conventional approach to space launches by not using established national ranges and by using their own rockets. One launched from a private island, the other is launching from international waters off the coast of California.

Both companies initiated contacts with the government on their own to get approval to conduct test launches. Although it was new ground for all concerned, they found the personnel in the agencies to be extremely cooperative and helpful. Nevertheless, their experience draws attention to what seems to be a formidable process.

As newcomers to the Federal process, Space Services, Inc. (SSI) and Starstruck failed to identify all the Federal players which had responsibility for approving some aspect of their respective launches. Already the number of agencies participating in the approval process, directly or indirectly, exceeds those originally identified by the two companies. The current list of involved Federal agencies includes: The Department of State (Office of Munitions Control), NASA, DOD, Air



Force, NORAD (separate from USAF), Navy, Office of the Secretary of Transportation, FAA, the Coast Guard, Materials Transportation Bureau, Bureau of Motor Carrier Safety, Bureau of Alcohol, Tobacco and Firearms, Federal Communications Commission, as well as state and local officials. It should be noted, that while each of these agencies played a role in the launch approval process, their level of involvement varied widely from simple coordination to actual review and approval.

The number of specific licenses or exemptions required depends on a number of factors, (e.g. whether the launch is in the United States territory or in international waters, whether imported rockets are used, etc.) Key licenses or exemptions include:

- Export License. Space launches are currently treated as an export of a product from earth to space. A launch firm must submit a formal application to the Department of State's Office of Munitions Control (OMC) for a "License for Temporary Export of Unclassified Defense Articles". The State Department reviews the proposed export from the standpoint of national interest, foreign policy and national security. DOD provides the national security review and may perform a cursory technical review as well. NASA reviews the application from the standpoint of assessing risk and technological feasibility. If the launch occurs in international waters, the OMC OMC also asks for an FAA review.

Because of the multiple agency reviews, this single license has taken between six and seven months to obtain. One applicant received its approval a day before the launch. The other received its approval one month before its launch.

- Frequency Application. To operate its communications and telemetry equipment, a launch firm must apply to the FCC for a radio operator's license and frequency assignments. As many as eight to twelve different frequencies could be required, some of which need to be dedicated solely to this event. Temporary use of frequencies appears to involve a simple application to the FCC. The approval process, in this case, has been fairly straight forward and prompt.
- Arms Import License. If any explosive devices are imported, such as was the case for SSI, which used imported rockets to calibrate its radar, a license is required from the Treasury's Bureau of Alcohol, Tobacco and Firearms.
- Transport of Hazardous Materials. Moving the rockets to their launch sites entails the transportation of hazardous materials in a manner other than specifically prescribed by Federal regulations. Launch firms must seek an exemption from the Materials Transportation Bureau (MTB), part of the Department of Transportation, for transporting fuels or other explosive materials required for launch.

Once an exemption to a specific procedure is obtained, it continues in force until the rocket design and/or procedures change.

As part of its exemption process, MTB issues a notice of the proposed action in the Federal Register for a 30-day public comment period. MTB then coordinates the proposed exemption with affected DOT agencies. This is likely to include the Bureau of Motor Carrier Safety if shipment will be by truck, and the Coast Guard if marine craft are involved. Any affected organization may add a requirement which is then included in the exemption approval.

- Airspace Restrictions. If the launch is to be from the U.S. or its territories, it is subject directly to FAA regulations 6/ concerning the operation of rockets in American airspace. FAA's primary concern in reviewing space launch applications is the protection of public and aviation safety. FAA has direct authority to provide or deny airspace clearance and requires that it be provided with the technical details of the launch vehicle, its trajectory, and overall safety/destruct features for its review. It must assure that the launch vehicle is generally capable of the performance characteristics ascribed to it, determine how much airspace must be cleared to protect aviation safety; and assure that the launch and operation of the vehicle will not endanger members of the general public.

From these examples, it should be clear that if there is to be a commercial ELV industry, we must make it easy for firms to deal with the Government. Once assured that national security, foreign policy, environmental concerns and public safety are protected (and these must always be the concerns of the Federal government), then the next objective is to make sure the industry's economic ability to develop is not hindered by needless regulation. One aspect of this will be to provide certainty and predictability in the licensing process.

Another problem is a tendency of Federal agencies to display an overabundance of caution. The experiences of Starstruck and SSI indicate that agencies have become involved in checking many facets of the request that go beyond their jurisdiction, resulting in considerable overlapping of technical data reviews by the Government. Part of the problem is that the industry is new, and the government has not clarified what information will be essential, nor does the industry know what to provide. One set of information requirements must be established, that will serve the needs of all the agencies involved.

Two other improvements are worthy of note: it would be very useful for the industry to have one point of contact when dealing with the government, and the processing time for license applications must be expedited. Thus the challenge, and one of the primary functions of the Department of Transportation, will be to streamline the regulatory process and minimize the cost and complexity to acquire a license to launch an expendable vehicle.

## OTHER ASPECTS OF COMMERCIALIZATION

The Department has encountered a broad spectrum of opinion about the prospects for a viable commercial ELV industry. Several companies have under development new launch vehicles. With varying success, they have elicited interest, and, in some cases, substantial financial backing. The Government is phasing out contract purchases of the Delta, the Atlas and Titan over the next few years, but NASA is under negotiations to provide a market for the latter two vehicles on a commercial basis.

Under commercialization, the market will dictate different sets of incentives and rewards than have been traditional in the space business. Companies will have their own money (or their financier's) at risk. They will have to establish new marketing networks. They must not only concern themselves with competing with the Shuttle and its impressive capabilities, but also with international competition from the Europeans' Ariane, Soviet Proton and Japanese launch vehicles. With payloads valued in the millions, reliability of the launch vehicle will remain as the most important criterion. Being commercial ventures, however, business will go to firms who can reduce their costs and/or supply a broad range of launching services, minimizing the headaches confronting their clients.

Quick, dependable access to space at low cost is critical to the rapid development of commercial space applications and maintaining American leadership in this area. As with all modes of transportation, the shipper should have a variety of options, and select the carrier who can deliver the payload required to the place required, at the time required, at minimum cost and at minimum risk. Our goal, at DOT, is to promote, encourage and facilitate the successful commercial ELV industry that will help bring this about.

## REFERENCES

- 1/ National Security Decision Directive: "Commercialization of Expendable Launch Vehicles," May 16, 1983. (Classified For Official Use Only).
- 2/ President's State of the Union Address, January 25, 1984.
- 3/ Reagan, Ronald. "Radio Address by the President to the Nation," January 28, 1984.
- 4/ Dole, Elizabeth Hanford. "Remarks to the Sixty-third Annual Meeting of the Transportation Research Board," January 18, 1984. Washington, DC
- 5/ See Hannah, David Jr. Testimony Before the Subcommittee on Space Science and Applications, May 4, 1983. Ninety-eighth Congress, First Session, or  
  
Nesgos, Peter D., "National Law and Commercial Activities in Outer Space. Specific Aspects of U.S. Law Applicable to Space Industrialization with Particular Emphasis on the Commercialization of Launch Vehicle Transportation," Chapter 4, September 1983  
Doctoral Thesis submitted to the Institute of Air and Space Law, McGill University.
- 6/ Aeronautics and Space. Code of Federal Regulations, Title 14, Part 101.

# CONCEPT FOR A COMMERCIAL SPACE STATION LABORATORY

by

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## ABSTRACT

This paper examines the concept of a privately owned and operated fee-for-service laboratory as an element of a civil manned space station, envisioned as the venture of a group of private investors and an experienced laboratory operator to be undertaken with the cooperation of NASA. This group would acquire, outfit, activate, and operate the laboratory on a fee-for-service basis, providing laboratory services to commercial firms, universities, and government agencies, including NASA.

This concept has been developed by Booz, Allen and Hamilton with the assistance of Dr. Myron S. Weinberg, under contract to NASA to identify, stimulate, and assist potential commercial users of a manned space station.

This paper examines a number of the issues which would be related to the concept, including the terms under which NASA might consider permitting private ownership and operation of a major space station component, the policies with respect to international participation in the construction and use of the space station, the basis for charging users for services received from the space station, and the types of support that NASA might be willing to provide to assist private industry in carrying out such a venture.

The objective of such a venture would be to provide a commercially operated space research facility for use by both private and public organizations. It will also enable involving the private sector in the construction of a U.S. space station, and would contribute to assuring U.S. leadership in the commercialization of space.

## INTRODUCTION

Private sector interest and activity in space is beginning to accelerate in the wake of President Reagan's dual commitments to a permanently manned space station and the promotion of private sector investment in space, both of which figured prominently in his State of the Union address of January 25, 1984. The President singled out the Space Station initiative in a subsequent radio speech, and in a line item in his Fiscal Year 1985 budget sent to the Congress on February 1. If this new level of interest is to be sustained and converted into commercial manufacturing in space, the ability to conduct research and development in space must be improved.

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\*Paper presented by Peter W. Wood.

With the high cost of space research facilities and equipment, few companies can afford to start their own R&D programs from scratch; instead they must develop cooperative arrangements with NASA through which they can use or modify existing pieces of equipment or jointly develop new ones. While in the short run this is probably the most effective approach for accomplishing commercial R&D, ultimately the private sector cannot and should not rely on the government for such support.

On the ground, similar private sector needs for facilities beyond those of any one company are met by commercial laboratories. These laboratories are equipped and staffed to conduct highly responsive short and long term research for their clients – both individual companies and government agencies – in a wide range of disciplines.

The concept of a commercial laboratory as an element of a manned Space Station is directly analogous to such a ground-based commercial laboratory. Operating long term in a microgravity space environment, such a laboratory would be well suited to the needs of many private sector companies to conduct research on phenomenology, processes, materials, and products as influenced by the attributes of the space environment.

This paper addresses the concept of the Commercial Space Station Laboratory (CSSL) in terms of:

- How it originated and why it is being considered
- Its possible configuration and features
- How it relates to the proposed space station
- How it would operate
- The issues to be addressed
- The current status of the CSSL concept.

#### WHY A COMMERCIAL SPACE STATION LABORATORY?

Man in space is turning the corner to a new era. The last twenty-five years have seen remarkable technological achievements, and extensive exploration – of the moon and most of the planets of our solar system. Now we are planning to develop the return on the investment which has gained our access to space. Already a thriving satellite communications industry, measured in billions of dollars, has been established. The next significant commercial step is expected to be the start of a material processing in space (MPS) industry.

President Reagan's State of the Union address of January 25, announcing his Space Station initiative and support of the commercial use of space has stimulated further interest in MPS. But each space product and process will depend on considerable research and testing before production can be undertaken. The space shuttle and the Spacelab carried in its cargo bay provide today's facility for conducting such research and testing in space, subject to the limitations of capacity and mission duration, measured in days. When the Space Station is deployed, in the early 1990's, it will include a laboratory enabling more extensive lab work on a long term basis.

During the Space Station user development work carried out for NASA by Booz, Allen & Hamilton, in which numerous non-aerospace companies were contacted, a number of companies were found to be reluctant to invest in hardware to conduct product research, but

willing to spend substantial money if the research could be purchased as a service. Such observations, combined with the determination that NASA was willing to consider proposals for private investment in modules planned as elements of the Space Station, inspired Booz, Allen's concept for the Commercial Space Station Laboratory – the space equivalent of a ground-based commercial laboratory serving the needs of commercial and government customers. Private investment in CSSL would not only provide a unique capability to a wide range of customers, it would enhance the probability of successful completion and deployment of the Initial Operating Capability (IOC) manned Space Station, by reducing the requirement for appropriated acquisition funds.

### WHAT IS THE CSSL CONCEPT?

The CSSL concept, then, provides for a privately owned, operated, and staffed, fee-for-service laboratory – on orbit in a microgravity environment – as an element of the initial Space Station capability. It would be acquired and deployed by a group of private technical and financial partners. The lab would be configured and staffed for research and testing in such discipline areas as biology, pharmacology, crystal growth, organic and inorganic separations, specialty glasses, and metallurgy. It would focus on both processes and products, taking advantage of the ability to conduct extended series of experiments with rapid interpretation, adjustment of parameters, and reruns. Users would include private companies, universities, government agencies, foreign countries, industry associations, and even individual researchers.

A representative Space Station concept is illustrated in Figure 1, showing how the Commercial Space Station Laboratory might be attached to the Space Station Multiple Berthing Adaptor, allowing access to all necessary services, the habitation and logistics modules, and extra-vehicular activity. Figure 2 shows an enlarged view of the CSSL module. This and subsequent figures display the results of preliminary engineering work performed by Booz, Allen with the help of McDonnell Douglas Astronautics Company.

A number of different activities can be accommodated, as indicated in conceptual drawings. Figure 3 shows typical racks of equipment for materials processing. Biological and metal production equipment would be provided in additional racks, shown in Figures 4 and 5. Figure 6 shows the configuration of the 'back porch' – an unpressurized pallet designed to be attached to the free end of the pressurized laboratory module to carry equipment which need not be pressurized, saving internal volume, and accommodating experiments operating in vacuum. As the need for other types of laboratory work develops, the lab can be reconfigured, in most cases without returning it to the ground. When demand projections support expansion, additional modules would be provided to the IOC Space Station or to the second Space Station.

### HOW DOES CSSL RELATE TO SPACE STATION?

The Commercial Space Station Laboratory would be an attached, manned, pressurized module of the Space Station, probably mated to a multi-ported docking adapter as shown in Figure 1. It would, in effect, be a tenant of the host Space Station, much like a tenant business in an industrial park on the ground, obtaining services from the host. The Space Station would thus provide electrical power, life support, communications and data handling services, logistics and storage, hotel services, and crew support (such as recreation and exercise) in addition to maintaining orbit and orientation, and the means for docking with the STS orbiter on resupply missions.

Accordingly, a key step is the negotiation of an appropriate agreement between the parties – NASA (or whoever operates the Space Station), and the commercial venture operating the CSSL.

The CSSL operation could be achieved in any of several ways:

- The lab – including the pressurized module and all installed or attached equipment – could be procured, owned, and operated by the venture. In this case the module could be fabricated to the same specifications as the government-owned modules and might well be built by the same contractor, possibly under an option to the government contract.
- The basic module might be provided by the government and sold to the lab venture for fitting out and operations.
- The module might be leased to the operator.
- The module and equipment might be government owned and leased to the operator.

The first, or “All-Up”, arrangement is the basic concept being explored. It requires the largest investment (and risks), but offers the largest return (through revenues, investment credits, and depreciation), and the most responsive service to customers through full proprietor control of configuration and outfitting.

#### HOW DOES THE CSSL ENTERPRISE OPERATE?

Individual customers purchase or contract for services with the CSSL operator, either on a project or task-by-task basis, or on a longer term task order or program. Services might involve: producing samples of material under various parametric conditions for testing or sample use in space or on the ground; testing samples in the space environment; testing operations of prototypes, hardware, or other equipment on specific materials in the space environment; developing and testing proposed processes; and conducting separations to isolate target substances.

The CSSL operator pays NASA (or the Space Station operator) for utilities, communications, data handling, accommodations, life support, and condominium charges related to an orbit tenancy. The CSSL operator pays the space transportation system operator for transportation of the lab crews, visiting researchers, supplies, samples and product return, and equipment for reconfiguration or depot level maintenance.

The CSSL operator plans and provides all lab-peculiar life cycle support, staffing, and staff training. NASA will probably certify staff for service on orbit, and review standards of training. NASA will provide training for Space Station emergency procedures.

#### WHAT ARE THE ISSUES?

One clear issue which must be studied is that of the size and type of market which may exist for the services of a Space Station laboratory by the time one can be made available.



Booz, Allen's commercial user development work for NASA has produced indications that interest in such activities exists, and NASA has encouraged Booz, Allen to pursue the concept with private investors and laboratory operators. Before detailed planning can proceed, however, a detailed market analysis must be conducted, both to determine the size of the market and the type of facilities that would be necessary, and to identify potential customers. Some of the interest which has been expressed has come from firms who would not have the resources to design and build complete space experiments, but would be capable of funding specific research if a properly equipped laboratory were available. As access to space improves and its cost is reduced, additional interest will be generated, and the CSSL will represent the most cost-effective way of pursuing that interest.

Another issue will be that of exclusivity – meaning whether there will be other laboratory facilities on the station, and who will be operating them. If NASA or some other entity will be in competition with the CSSL, it could reduce the potential profitability and savings to the government which CSSL would make available.

Related to this is the question of the basis on which NASA will charge tenants for the services that the Space Station will be providing to the CSSL. Until this policy is known, it will be difficult to estimate those costs and hence completely understand the economics of CSSL operations.

The issue of how international participation in the Space Station program will be handled may have a significant effect on how (or whether) a CSSL is possible. If the European space community, in the wake of its successful Spacelab effort, provides a major portion of the laboratory facilities, the opportunity for commercial ownership and operation of the laboratory could be preempted. The decision on international participation will also be affected by the degree to which the United States wishes to limit technology transfer in the construction of the Space Station, cast against the desire to incorporate extensive international cooperation in the program.

In addition, the questions of how to coordinate the private sector development of the CSSL with NASA's development of the Space Station, the need to reduce the time between the major investments and the beginning of revenue production, the tradeoff of investment and risk between NASA and the investors, and even the question of how the Space Station will be configured, will have a significant effect on the way that the CSSL concept can be developed.

#### WHAT IS THE STATUS OF CSSL?

NASA has repeatedly expressed its interest in incorporating private sector activities in its Space Station program, and NASA Administrator James Beggs stated in the NASA budget briefing (January 31, 1984) that the Agency would be willing to incorporate private sector investment in a module in its program planning. With this indication of interest from NASA, one of the next steps will be to arrange a meeting of interested private sector investors with NASA officials to examine the process through which such an investment should be made.

In parallel with these next steps, the analysis of the issues identified above must be carried out, and alternative means of structuring an agreement with NASA must be drafted and examined. Above all, it is important that interested private sector individuals and organizations

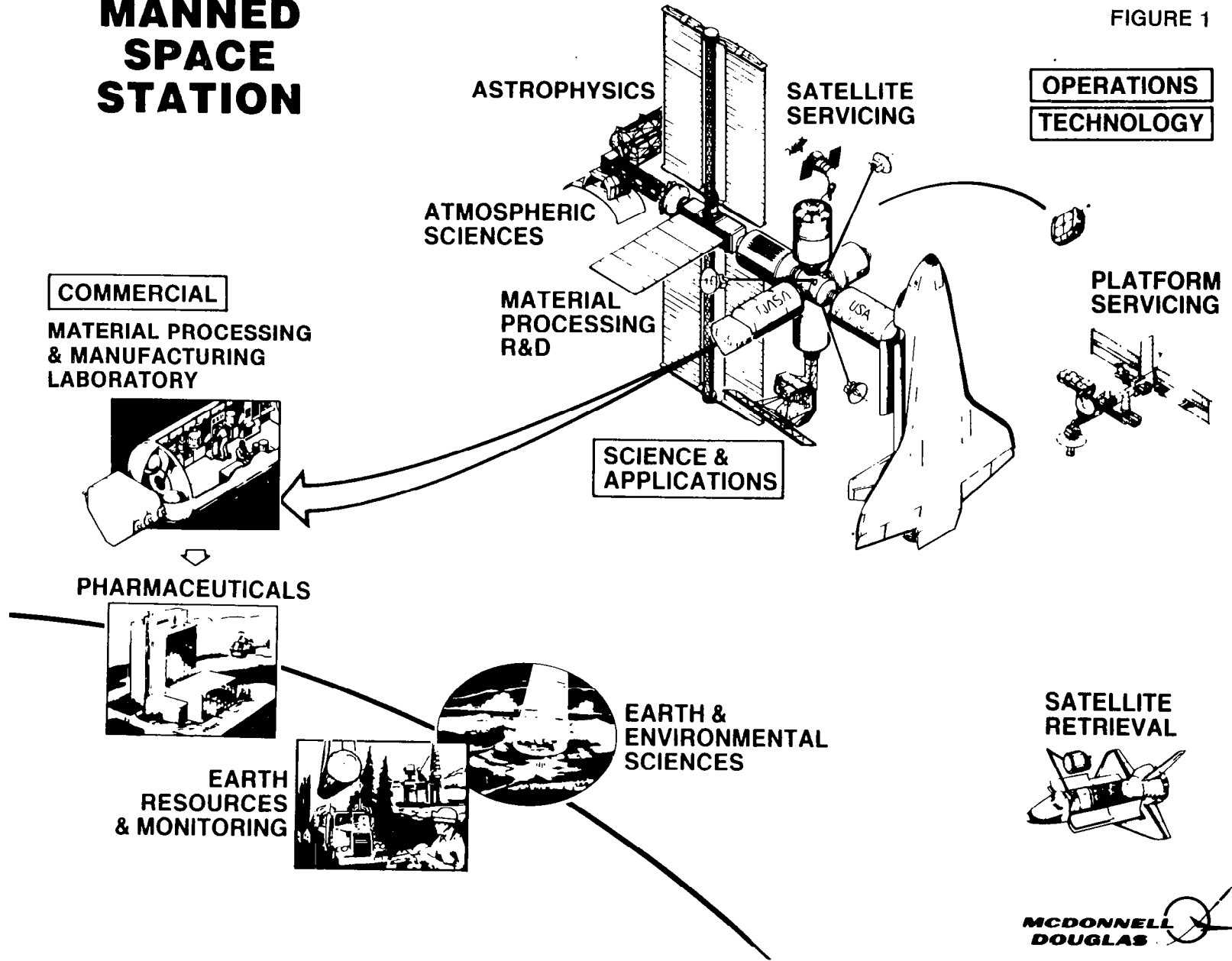
come forward and participate in the development of the concept, before Space Station plans are finalized.

### AN OPPORTUNITY FOR U.S. INDUSTRY

The Commercial Space Station Laboratory represents a significant opportunity for U.S. industry to convert this country's considerable investment in space technology into a position of leadership in the developing space frontier. If the American people are to reap the benefits of this new frontier, it is essential that the government encourage and support the private sector in bold ventures such as the Commercial Space Station Laboratory.

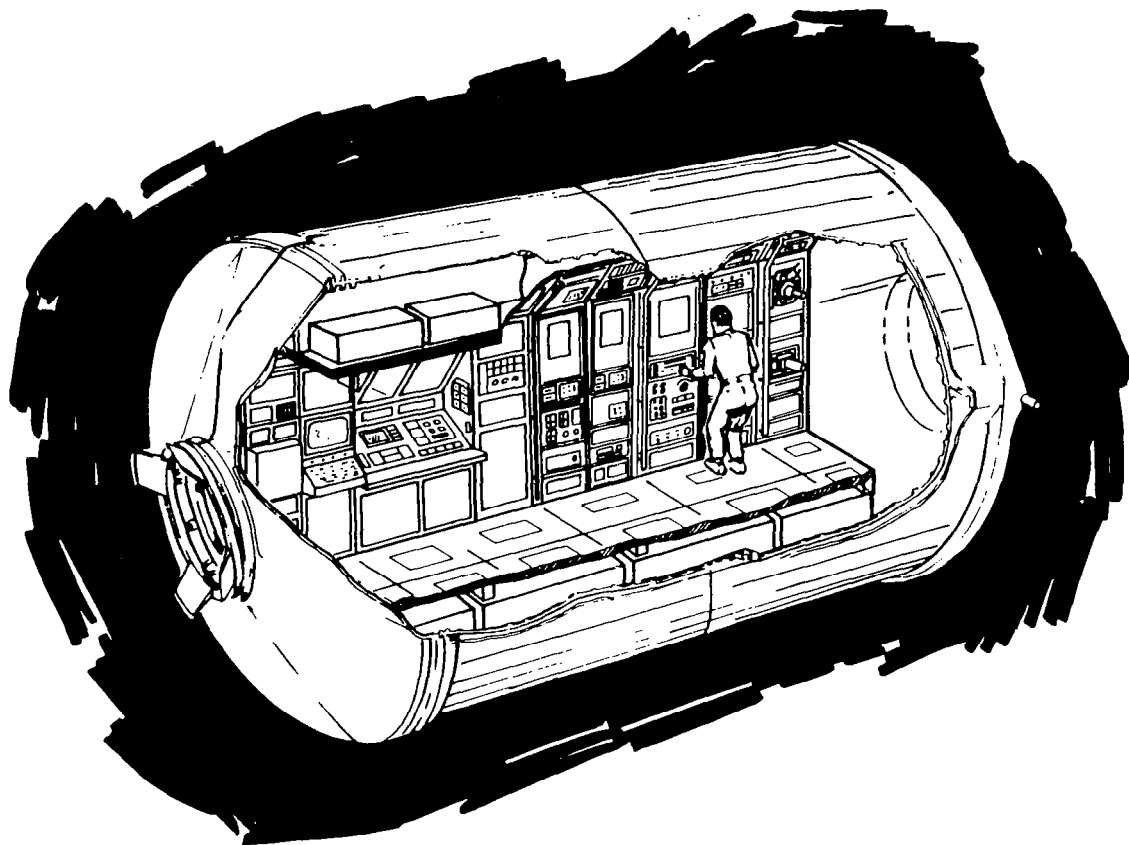
# MANNED SPACE STATION

FIGURE 1

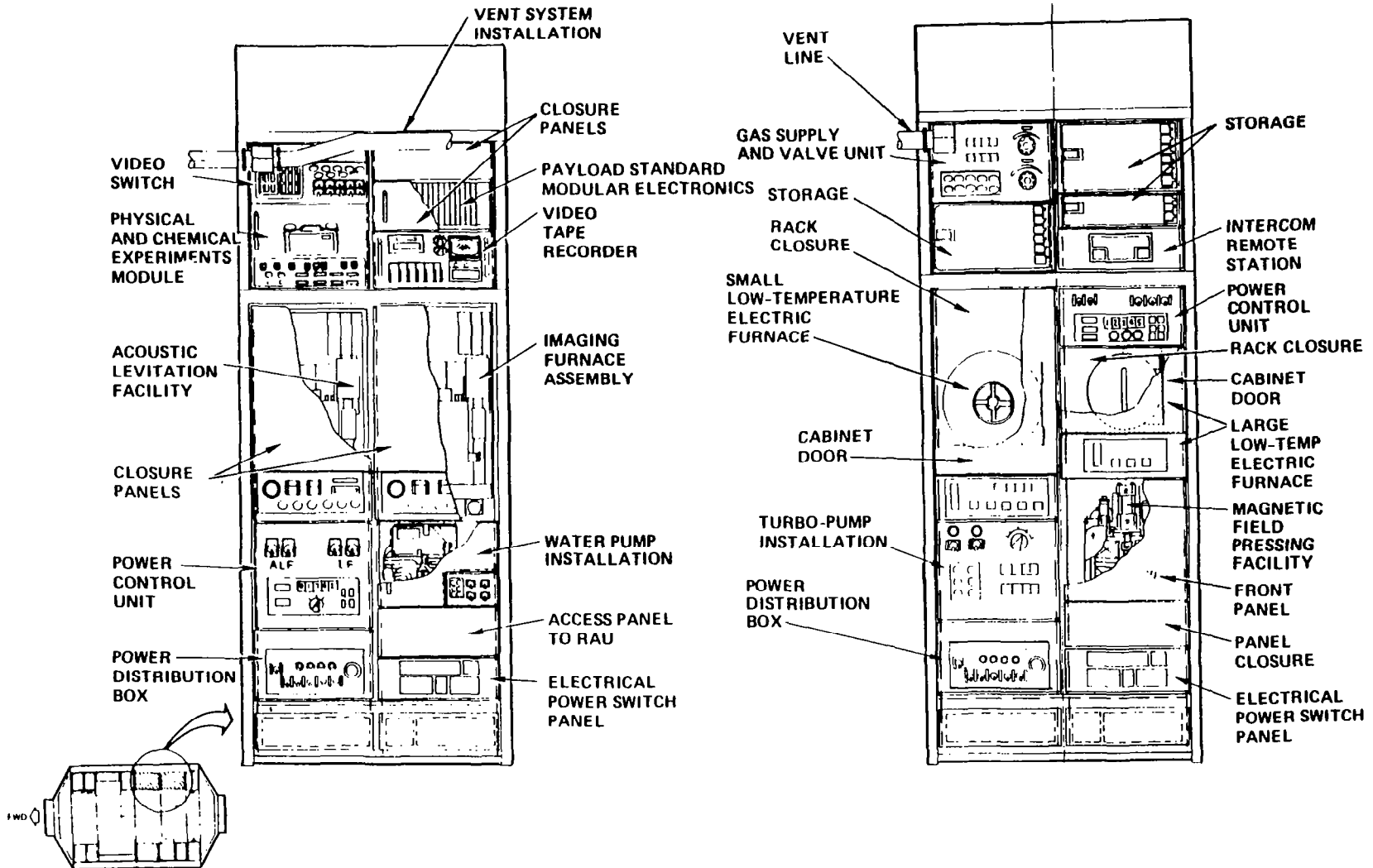


FOR  
BOOZ ALLEN & HAMILTON INC.

# COMMERCIAL FEE-FOR-SERVICE LABORATORY

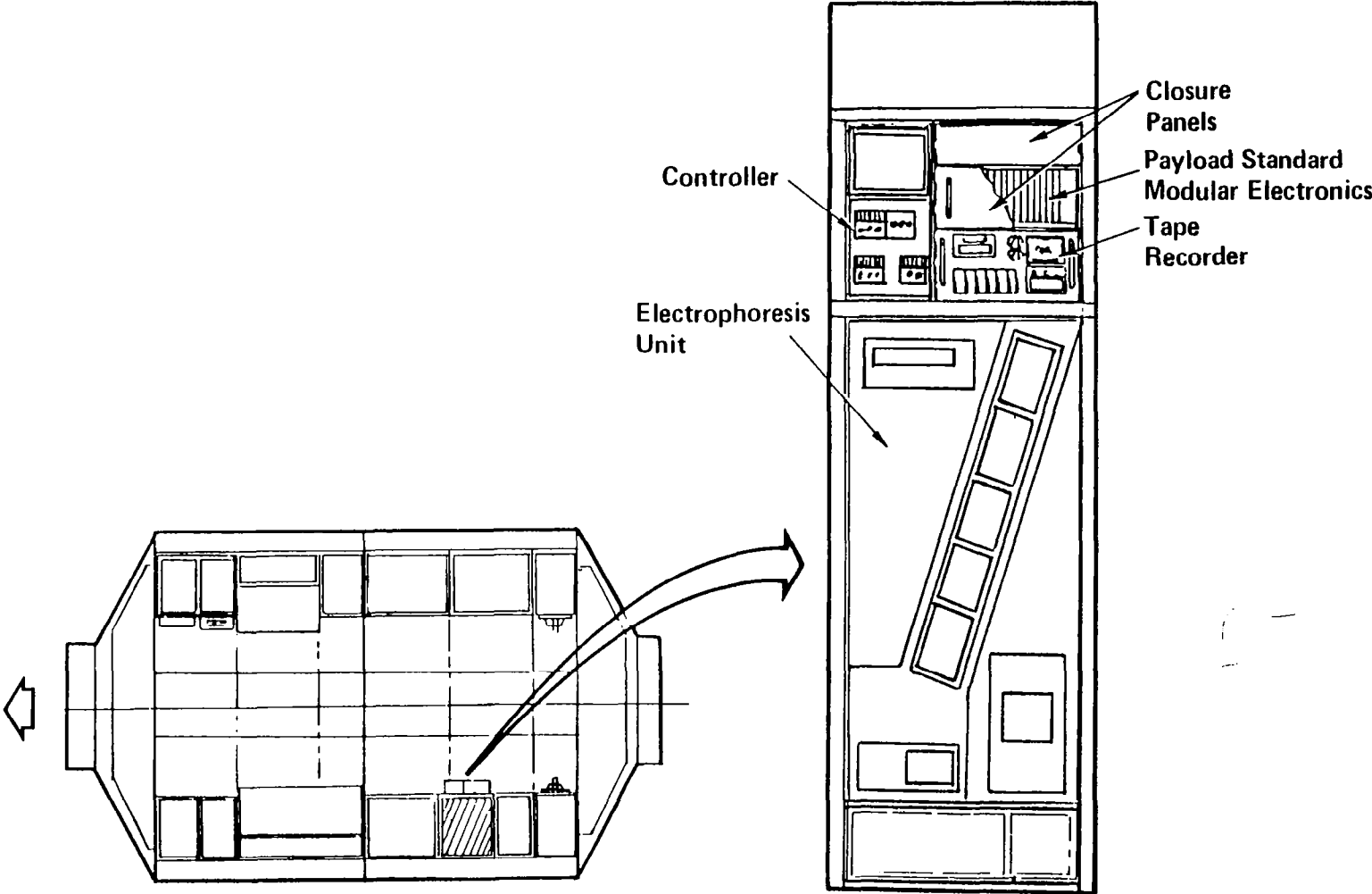


# TYPICAL MATERIAL PROCESSING EQUIPMENT INSTALLATION



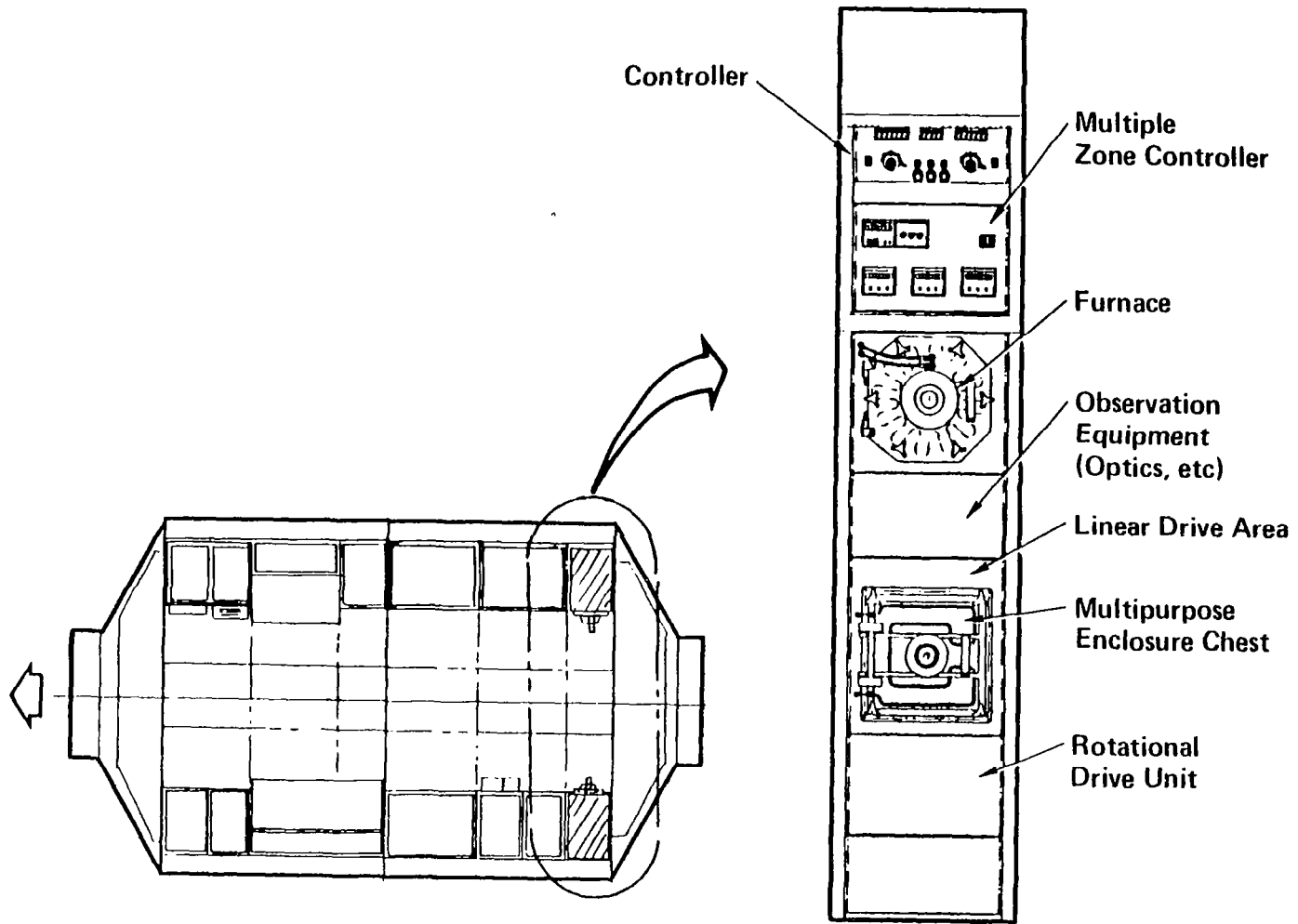
# TYPICAL BIOLOGICAL EXPERIMENT INSTALLATION

FIGURE 4



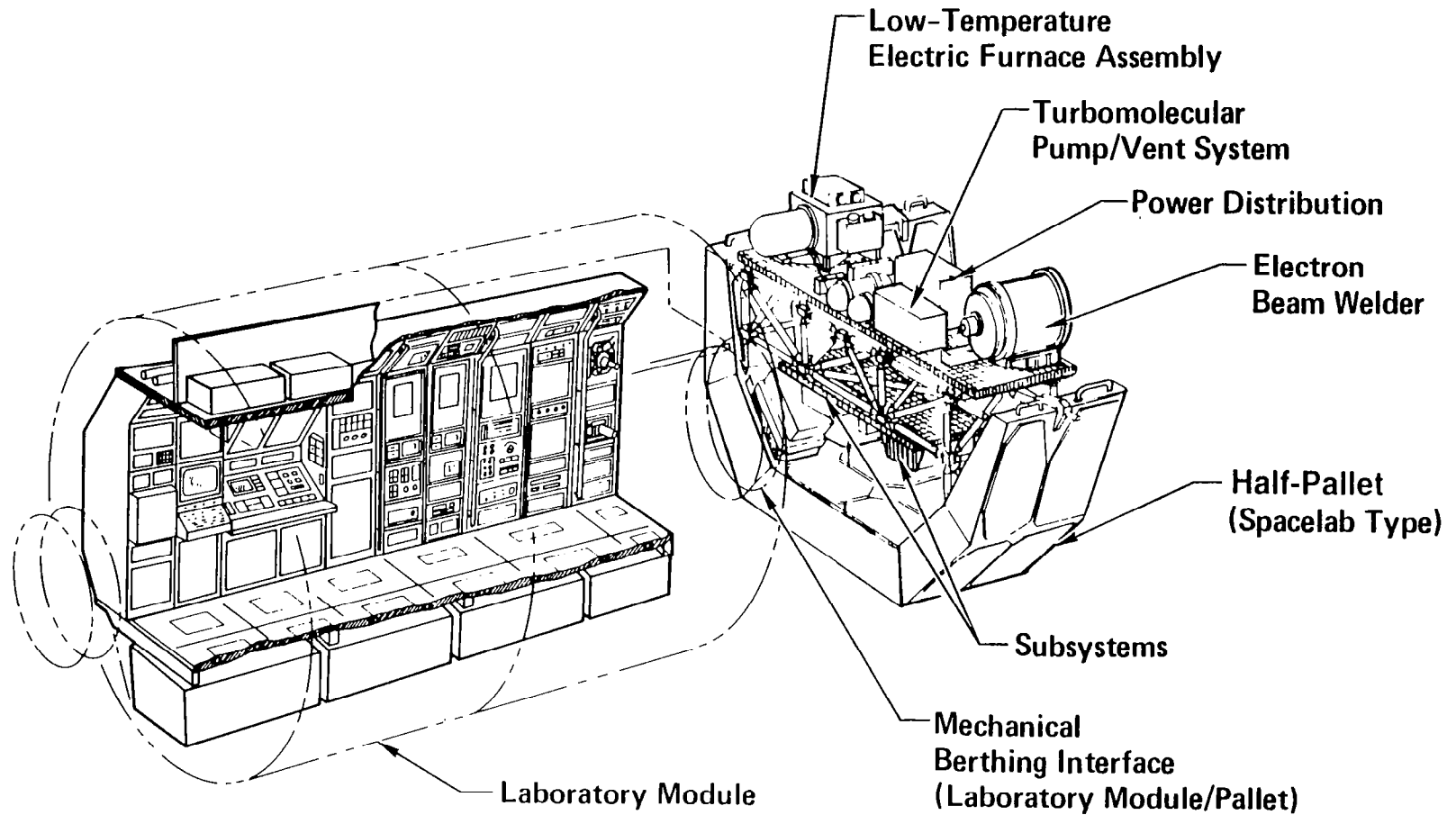
# TYPICAL METAL PRODUCTION EXPERIMENT EQUIPMENT

FIGURE 5



# COMMERCIAL LABORATORY - MATERIALS PROCESSING PALLET INSTALLATION

FIGURE 6





# ROLE OF SPACE STATION – THE HOW OF SPACE INDUSTRIALIZATION

by

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## ABSTRACT

An industrial revolution in space is underway with much of the required base for space industrialization currently available or in development. Logistics can be provided by the Space Shuttle. Launch facilities are in place. Ground mission and operations and an associated technological infrastructure are available. Business procedures and precedents can be modeled after or derived from the successful space communications industry. Industrial interest in all aspects of space, particularly materials processing in space, is growing. There is an increasing appreciation of the potential utility of space technology for both research and industrial purposes. Moreover, the President has proposed a national imperative which would place key defensive systems in space.

One vital element is yet to be provided — a permanent operating base in space. The space station, to which we are now committed, will provide the needed support for systematic exploration and exploitation.

This paper considers the roles of the Space Station, as an R&D facility, as part of an industrial system which supports space industrialization, and as a transportation node for space operations. Industrial opportunities relative to these roles are identified and space station concepts responsive to these roles are discussed in this presentation.

## INTRODUCTION

For the past twenty-two months, following the successful flights of the Space Shuttle, NASA has conducted preliminary definition efforts in support of future decisions regarding a space station program. These efforts have been relatively modest in scope and coordinated by Mr. John Hodge, the Director of NASA's Space Station Task Force.

Earlier this year, President Reagan requested an interagency study to establish the basis for an Administration decision on whether to proceed with development by NASA of a permanently-based, manned space station. The study, which took place over the spring and summer, is now complete. The analysis addressed issues relating to leadership in space, fulfilling mission requirements, foreign policy and national

security implications, and economic impacts. Participating in the study were NASA, the Department of Commerce, the Department of State, the Department of Defense, the Arms Control and Disarmament Agency, and the Office of Science and Technology Policy. Based on the results of these activities, President Reagan, in his State-of-the-Union Address on January 25, 1984, announced the commitment of the United States Government to establish a permanent manned presence in space: THE SPACE STATION. This major decision provides the impetus for space industrialization.

Up to now space program activities have been mainly directed at exploration. We have launched a number of probes, observatories, measurement devices, etc., to explore near Earth and deep space. These missions have been largely single point, discrete activities. With a few notable exceptions like the Apollo mission, data returned to Earth has been mostly in the form of electronic or photographic images.

The country has reaped huge rewards in scientific advancements, national prestige and technology spin-offs for our early space exploration activities. In addition, some overall applications with concrete economic benefits have resulted. These first order applications are primarily based on the new perspective achieved from the "high ground" of space.

Space provides a global perspective, thus Earth observations and weather satellites are readily evident applications. Space provides a very convenient way to relay line-of-sight communication signals. This latter application is now a full-fledged revenue producing industry. Again, these applications do not depend, but will be aided by routine, frequent access to space. Data to and from these space facilities are simple electronic signals. However, the operations of such facilities could be enhanced by routine frequent access to space simply by making user-shared launches. Moreover, a new permanent presence in space will make operations even more convenient and cost effective through resupply and repair activities.

Beyond these communication and observation applications there are a number of other scientific and economic applications of space. These applications, like Microgravity Materials Processing in Space (MMPS), are not as readily evident. For example, the theoretical basis for the effects of gravity-driven convection on processes like crystal growth lies in a differential equation on gravity driven convection. Unlike results from earlier space applications, the results of these processing experiments are contained in the sample, for example a crystal, which must be physically returned to Earth for subsequent analyses and use.

Therefore, these (and other) second order applications require not only frequent, convenient access to and from space, but they should profit greatly from a laboratory in space. After all, the type of science and technology encompassed by MMPS is high technology even on Earth. This kind of technology is constantly pushing the "state of the art."

On Earth, progress in advanced technology is made through sustained, systematic laboratory research. The same is true for space. The new working environment in space requires that we have a permanent presence there.

## **FUNCTIONS OF THE SPACE STATION**

Based upon our analysis and that of our industry contractors, it is clear that the space station will serve a number of functions. As shown in Figure 1, the space station should provide:

- A laboratory in space, for the conduct of science and the development of new technologies;
- A permanent observatory to look down upon the Earth and out at the universe;
- A transportation node where payloads and vehicles are stationed, processed and propelled to their destinations;
- A servicing facility, where these payloads and vehicles are maintained and if necessary repaired;
- An assembly facility where, due to ample time on orbit and the presence of appropriate equipment, large structures are put together and checked out;
- A manufacturing facility where human intelligence and the servicing capability of the station combine to enhance commercial opportunities in space; and
- A storage depot where payloads and parts are kept on orbit for subsequent deployment.

For example, as traffic increases, more and more operations will be done in space. More payloads will be left in storage for later assembly or use. After all, the Shuttle can lift around 65,000 pounds, but can return (land) with only 32,000 pounds. This alone dictates the need for orbital storage and operations facility. Such an "orbital depot" or transportation node in space is clearly required to support industrial space operations. Industrial operations must be cost effective. Since transportation costs are a major part of any space endeavor, these costs must be shared whenever possible. The Space Station in its high traffic orbit will make this feasible. After the Space Station becomes operational, flights of the Shuttle need never go to orbit less than 100 percent loaded.

Perhaps more important than any of these individual points, however, the space station could also lead to important activities and functions that we can not predict today.

## **ARCHITECTURE**

At this point, it is appropriate to comment conceptually on what NASA has in mind for the space station. The term "conceptually" is used because we do not have a space station design. There have been many illustrations of space stations, and while these are nice pictures, they do not represent a NASA configuration. The space station is conceived as a multi-purpose, permanent facility in low-Earth orbit, comprising both

manned and unmanned elements, that significantly enhances the efficiency of our operations in space. The station could consist of a manned base and associated unmanned platforms as shown in Figure 2. These platforms (there might be only one to start with) would be discipline oriented and be tended from the base by an Orbital Maneuvering Vehicle (OMV) or by astronauts conducting Extra Vehicular Activity (EVA). A tether could also possibly be employed.

The base, as currently conceived, is a cluster of functionally oriented modules. The key elements, as presently defined, include a utility module to provide essential services, such as power and thermal management to the cluster, a berthing and assembly module, a module for living, a laboratory module for working, a logistics module for supply and replenishment, and pallets or platforms to which are attached scientific instruments and repair equipment for both the base and the platforms.

The concept of the Space Station encompasses both manned space flight and unmanned spacecraft activities. The Station will employ astronauts in tasks and jobs where the presence of man is uniquely valuable. Certain activities, particularly those of a routine nature or those that can be programmed in advance, are better suited for automated systems. The challenge for NASA is to design a space station that achieves the best of both modes.

### **BENEFITS**

The Space Station Mission Analysis Studies, the concurrent Mission Requirements Working Group and panel activities, and the culminating Space Station Mission Requirements Workshop have all contributed to a better understanding of potential Space Station benefits. Just as the Space Station will support a diverse set of mission activities, the benefits will occur in many diverse ways. The potential benefits may be generally summarized as follows:

- 1) Mission enablement and enhancement due to resourceful manned presence;
- 2) Creation of a viable commercial activity, particularly in space materials processing;
- 3) Significant cost savings due to more efficient transportation and servicing operations; and
- 4) Tangible and intangible societal benefits related to mission results, space R&D applications, and national prestige.

The Space Station will contribute significantly to the goals of our national space policy to:

- Maintain United States leadership in space;
- Obtain economic and scientific benefits through the exploitation of space;

- Expand United States private sector investment and involvement in civil space and space related activities;
- Promote international cooperative activities in the national interest;
- Cooperate with other nations in maintaining the freedom of space for activities which enhance the security and welfare of mankind; and
- Strengthen the security of the United States.

Civil leadership in space means preeminence in space technology, preeminence in manned space operations and preeminence in space science and applications. At a time when U. S. leadership is at issue in certain disciplines of science and in a number of industries, the commitment to the Space Station is a welcome and reassuring reminder of our capacity to lead.

Already economic benefits accrue to the United States from the exploitation of space. The communications industry is in large part space-based, which is responsible for improved service at lower cost. This was made possible by federal research to develop the initial technology and to reduce the risk to an acceptable level, thus enabling private venture capital to launch a new highly successful business enterprise. The Space Station should do the same for the field of materials.

Benefits to the United States also accrue from the science conducted in space. Knowledge of the Earth and a greater understanding of our own solar system and the many galaxies of the universe has been gained from the scientific spacecraft we have placed in orbit and sent out to our sister planets. The Space Station will be a valuable addition to the nation's scientific assets.

In the future, NASA hopes to increase the benefits our many activities in space provide. These activities, in science and applications, in launch vehicles, in technology and in the area of commercial endeavors, offer tremendous potential for the years ahead.

In many instances, foreign aerospace capabilities are now fully mature and competitive with those of the United States. Thus, other nations can make genuinely significant contributions to the Space Station. These contributions, if determined to be appropriate, would have the effect of adding to the Station's capabilities at no additional cost to the U. S. Treasury.

### **THE SPACE STATION AND INDUSTRY**

The Space Station will be the hub around which future space activities revolve. These capabilities relate to the broad categories of:

- 1) Space science and applications
- 2) Technology development
- 3) National security
- 4) Commercial endeavors

In the following sections, the foreseen roles of the Space Station for each of these categories are summarized and potential involvements for industry are identified.

### SPACE SCIENCE AND APPLICATIONS

Space science and applications activities are those which are primarily planned, funded, and conducted by the government for the advancement of scientific understanding and its potential applications. These include activities in the areas of:

- Astrophysics -- the study of the universe and of the sun as a star;
- Solar System Exploration -- the study of the planets and their environment;
- Earth Science and Applications -- the study of the planet Earth including the dynamics and interaction with the sun;
- Life Sciences -- the study of life as it is affected by its environment in space and development of life support systems.
- Materials Sciences -- the study of the production of special materials and processes in the absence of gravity; and
- Communications -- R&D to exploit additional space-based communications techniques.

Together, these activities can make use of four classes of capabilities to be supplied by the Space Station. These are: (1) a pressurized laboratory (i.e., manned micro-gravity facilities); (2) a base for operating attached payloads (i.e., sensors); (3) a servicing station for associated free-flyers; and (4) a transportation node for a wide spectrum of R&D payload operations.

A number of science and application missions will be enabled by the Space Station. For example, some materials processing R&D and all pilot plant demonstrations require longer, man-tended mission durations, longer than those available on the Shuttle to demonstrate the viability of materials space processing for commercial use. The life sciences program (consisting of a health maintenance and clinical research facility, a human research laboratory, an animal and plant vivarium and laboratory, and controlled environment life support system (CELSS), experimental systems, pallet, and dedicated module) will require long duration, man-tended missions. The Light Detection and Ranging (LIDAR) facility will require frequent servicing and configuration changes for evolutionary development combined with an extended mission duration to be economically feasible. An experimental geosynchronous platform will be enabled in the sense that Space Station deployment and alignment will allow larger antennas than can be packaged in the Shuttle bay.

As will be later discussed, activities in this category, even though the government has prime responsibility for their planning and conduct, will require many support service functions which may be provided by the private sector.

## TECHNOLOGY DEVELOPMENT

Technology development encompasses experimental activities for advancing space technology. The broad scope of these activities will enhance space science and applications, commercial uses, national defense, and overall capabilities in space. These activities, as categorized by NASA/Office of Aeronautics and Space Technology (OAST), encompass the following disciplines:

- 1) Materials and structures
- 2) Energy conversion
- 3) Computer science and electronics
- 4) Propulsion
- 5) Controls and human factors
- 6) Space Station systems
- 7) Fluid and thermal technology

Candidate technology development missions have been identified based on their need for elements of the space environment plus one or more of the operational conditions made available by the Space Station. Operating conditions offered by the Space Station will include:

- Space environment (low-gravity, low pressure, low temperature, plasma, radiation)
- Human interface/experiment accessibility
- Ability to handle large sizes (with EVA and manned maneuvering units (MMU))
- Long-term operations capabilities
  - Iterative adjustment/testing
  - Evolutionary development (e.g., optimal environmental control and life support system (ECLSS))
  - Long duration exposure, removal, inspection or replacement
  - Utilities and support systems

As with the space sciences and applications, current activities in the category of technology development are primarily planned, funded, and conducted by the government. As needs for such activities to support commercial ventures become more apparent, we should expect to see increasing involvement by the private sector in their planning, funding, and conduct. Such activities, whether sponsored by the government or the private sector, will also require many support services which may be provided by the private sector.

## **NATIONAL SECURITY**

It is evident that space provides a global perspective and can be used for surveillance, navigation and other military operations. (However, to date, firm military needs and uses for the Space Station have not been identified.)

All of the missions in this category will most likely be planned, funded by and conducted under the direct auspices of the government. As with the other categories, however, there will be many areas in which the private sector may provide support.

## **COMMERCIAL ENDEAVORS**

Commercial activities relate to products, processing and services in which elements of the private sector, anticipating a reasonable economic return, may be expected to directly participate in their initiation, planning, funding and conduct. These activities include:

- 1) Earth and ocean observations
- 2) Communications
- 3) Materials processing in space
- 4) Commercially provided support services

### **1. Earth and Ocean Observations**

Satellite technologies have revolutionized our ability to monitor the Earth's environment and its resources. Meteorologists, oceanographers, hydrologists, geologists, farmers, foresters, and those in many other disciplines now look to space to learn more about the Earth.

Currently, meteorological satellites provide global meteorological data to support operational and experimental portions for world "weather watches" in addition to supporting international weather agencies and U. S. military requirements.

Capabilities from space for navigation and monitoring of sea states offer significant advantages. For example, a most important parameter in automated ship routing is sea state; however, winds, currents and hazards to navigation (fog, snow, ice) are also significant. Reliable sea state analysis and predictions can reduce transit time up to 10 percent resulting in savings of \$15,000 to \$40,000 for a typical Pacific voyage. Furthermore, the modern fisherman needs reliable and accurate marine weather information along with knowledge of oceanographic conditions affecting fish feeding such as water temperature and color/clarity structures. Weather influences all aspects of fishing operations. Wind and wave conditions affect vessel safety, the ability to deploy and secure gear, and travel time from the fishing grounds to processing plants.

Imagery of the Earth from space will provide a wide variety of such useful data applicable to polar region ice surveillance, agriculture, hydrology, geology, land use, environmental monitoring, and marine and ocean resources.



The Space Station (and future Space Stations in highly inclined and polar Earth orbits) will provide:

- An in-space laboratory for development and verification of remote sensing sensors and imaging techniques
- Manned platforms for targeting and selective control of the imaging processes
- Assurance of continuity of data
- Timely reaction to targets of opportunity

The high initial costs and undefined market potential will limit privately funded systems for Earth and ocean observations. With the advent of the Space Station (and associated platforms), investment costs may be substantially reduced and observations can be adapted to specific requirements. This will enhance involvement of the private sector. Furthermore, as the hardware evolution proceeds to space stations and platforms in polar and geosynchronous orbits, there should be increased impetus for involvement of the private sector.

Currently, the private sector is substantially involved in the processing and interpretation of Earth and ocean observation data. For this potential to be fully realized, the government should involve the private sector more in planning for such missions and provide for greater access to raw data. Further, the government should be prepared to relinquish some of its responsibilities in the data processing and interpretation field to the private sector.

## **2. Communications**

Communications has been the major successful space commercialization activity to date. Communication satellites at geostationary altitudes have been used commercially for approximately 15 years. There has already been a significant involvement of the private sector in the ownership and operation of these satellites. Based on projected markets and on NASA's current plans for enhancement of in-space capabilities through continuing R&D of space transportation and on-orbit systems, private sector ownership and operation of commercial communication satellites should continue to increase as shown in Figure 3. Transportation costs to orbit should progressively decline with first, the expanded use of private sector commercially owned and operated expendable launch vehicles, then through the use of the Space Shuttle with government and commercially owned expendable orbital transfer vehicles, and ultimately, through use of the Reusable Orbital Transfer Vehicle in combination with multiple payload carriers and the spectrum of envisioned on-orbit capabilities to be provided by the Space Station, orbital Maneuvering Vehicles, etc. The capability for on-orbit servicing should further reduce the cost of ownership of these systems by allowing for lower cost designs, improved reliability, and longer overall lifetimes for the systems. Ease of replacement will allow for more continuity of the provided communication services.

Communication satellites, whether owned and operated by the government or the private sector, will utilize a wide range of Space Station provided support services, many of which may well be provided by the private sector. These include:

- 1) Communications tests — These will be accomplished on Earth and in space, and will involve basic and applied research and development, subsystem and system testing, and systems applications experiments. The in-space activities would include:
  - a) Testing of large deployable antennas
  - b) Testing of laser intersatellite links
  - c) Development of spaceborne interferometry technology

Such testing could involve the ownership and operation by the private sector of a communications test lab (attached to the Space Station) and free-flying platforms.

- 2) Communications satellite delivery and deployment (to include on-orbit assembly)
- 3) On-orbit servicing

### **3. Materials Processing in Space**

There is the potential for large stable markets for high-value, low-mass items and materials (particularly for use by health, electronic, and defense related activities) which require the special environment of space for their processing. A cross section of MPS processes and typical experiments are identified in Figure 4. It should be emphasized that the majority of MPS research is being done for scientific reasons. However, some of this work has engaged industrial interest and participation. In-space laboratory testing for development of these processes has already begun. A current set of experiments aboard the Space Shuttle, i.e., those associated with a continuous-flow electrophoresis system for pharmaceutical products, are being conducted under a Joint Endeavor Agreement (JEA) between the McDonnell Douglas Corporation/Johnson and Johnson, and NASA. As is well documented from previous studies, the private sector has a strong interest in other similar in-space experiments and tests leading to commercialized in-space processing. Such activities can ultimately lead to private sector ownership and operation of Space Station modules or other on-orbit processing facilities.

An unexpected bonus was recently realized when the MMPS Program made its first sale. The Monodisperse Latex Reactor System (MLRS) was flown on the Space Transportation System (STS) -3, 4, 6, 7, and 11 and produced highly uniform latex spheres in sizes up to 30 micrometers. The quality of these spheres is considerably better than those produced on Earth. This experiment was conceived and developed for scientific studies of polymerization, yet has yielded both scientific data and potential applications. The National Bureau of Standards (NBS) has requested that NASA provide spheres of 10, 30 and 100 micrometers to be sold by the Bureau as "Standard Reference Materials." On the order of fifteen grams of the ten micrometer spheres produced on STS-6 are being turned over to the NBS. Plans call for these to be packaged into 3 milliliter vials and sold for \$350.00 per vial. The MLRS will be reflown on at least three subsequent Shuttle flights to produce the 35, 60 and 100 micrometer spheres for the NBS. It is anticipated that this activity will become a commercial endeavor after this series of flights and will be implemented through a Joint Endeavor Agreement with industry.

The manufacture of high-quality metals, crystals, glasses, and chemicals requires high-temperature furnaces of various capabilities, chemical reaction chambers, levitation systems, and controlled chamber atmospheres and pressures. Presently on Earth, each manufacturing plant is tailored to the subject material. Overcoming practical problems of weightlessness will result in new designs and require demonstration and pilot plant activity. The repetitive nature and slow time constants of most high-temperature and vapor processes require long periods in orbit. The Space Station will be an attractive orbital vehicle to accomplish much of this activity because it will eliminate the requirement to re-orbit heavy support equipment and will allow continuous operation with technical risk kept to a minimum. Much technological development for levitating free-floating specimens of high-temperature melts is required prior to the operational phase.

Prior to the Space Station, we can expect further private sector involvement using the Shuttle accommodations and Shuttle dependent carriers for experimentation leading to in-space processing procedures and subsequent processing of small production quantities. The Space Station will provide for longer term experimentation and increased space for more complex investigations and larger production quantities as shown in Figure 5. With additional platforms and the advent of the Orbital Maneuvering Vehicle, separate processing and experimental and processing facilities could evolve.

Obviously, all in-space processing activities, both those of the government and the private sector, will require a broad spectrum of support services, many of which may be provided by the private sector.

#### **4. Commercially Provided Support Services**

It is expected that the government will have the primary role for the funding and conduct of missions in the areas of space science and applications and national security and will have a major role for funding and conduct of technology development activities. These missions, however, will require a complete spectrum of support services, both ground and space-based, many of which can be provided by the private sector. Similarly, government and commercial missions in the areas of Earth and ocean observations, communications, and materials processing will also require such support services.

Support services may be divided into five major categories as follows:

- 1) Support to program and project management
- 2) Transportation and logistics services
- 3) In-space testing and assembly/disassembly services
- 4) Payload servicing
- 5) Facility operations and support services

## **SUPPORT TO PROGRAM AND PROJECT MANAGEMENT**

The private sector has historically provided and will continue to provide prime contractor support for the development, production, deployment, and operations of systems. As prime or support service contractors or subcontractors, elements of the private sector have also provided a myriad of program and project management support functions.

Such support to planning, research and development, production, and operational programs and projects will continue. With the emphasis on commercialization, the trend will be toward more delegation by the government of responsibilities in these areas to the private sector. This will be particularly true in the areas of planning wherein the private sector can be expected to exert more influence as its activities become a more integral part of the overall space activities.

## **TRANSPORTATION AND LOGISTICS SERVICES**

The category of launch and logistics services encompasses:

- 1) The Earth/space and in-space transfer of personnel and cargo, for example:
  - a) Launch
  - b) Deployment (including initial orbit and/or trajectory adjustments)
  - c) In-space transfers (including retrieval of payloads)
  - d) Removal and disposal of space debris
  - e) De-orbiting and Earth recovery of systems from space
- 2) Warehousing and provisioning of space consumables and spares
- 3) Operation, servicing, maintenance, and repair of all involved hardware systems
- 4) All support services related to the above.

Such services could involve private sector operation and/or ownership of transportation systems (ground and space) such as the Space Shuttle, the Space Shuttle Derived Launch Vehicle, the Aft Cargo Carrier of the External Tank, Expendable Launch Vehicles (ELV's), expendable and reusable Orbital Transfer Vehicles, Orbital Maneuvering Vehicles, attitude controlled platforms, deployment mechanisms, and Earth-based multiple payload carriers, and Earth-based recovery systems. Furthermore, they could involve operation and/or ownership of ground and space launch/communication and tracking/hangar/loading/fueling/warehousing facilities.

The private sector has already become involved in transportation and logistics services at both the primary and support levels. At the primary level, the private sector is currently planning to provide and launch expendable vehicles (for example, the General Dynamics Atlas Centaur and the McDonnell Douglas Thor Delta). Furthermore, NASA and the Orbital Systems Corporation have entered into a Joint Endeavor Agreement wherein Orbital Systems Corporation, with certain incentives and support provided by NASA, will develop and operate the Transfer Orbit Stage (an expendable stage

primarily for interim transfer of payloads from Low Earth Orbit to Geostationary Orbit prior to the advent of the Reusable Orbital Transfer Vehicle.

Other than ownership, elements of the private sector could have the responsibility for operation of these primary systems. This could be accomplished under either of two arrangements: 1) contracts with the government for such operations, or 2) leasing by the government of transportation hardware to the private sector for private sector operation.

Considering the smaller elements of the Space Transportation System it is reasonable to assume that many could be operated, if not owned (if developed under suitable agreements with the government) by elements of the private sector. Those owned could be operated by their private sector owners or leased to the government and/or leased to other elements of the private sector for operation.

Short of ownership/operation of transportation and logistics systems, there is and will be a broad spectrum of opportunities for provision of support services by the private sector. The private sector is currently significantly involved in ground-based support services for transportation and logistics. It is logical to assume that private sector provision of such services will be extended into space as space-based transportation and logistics systems evolve.

#### **IN-SPACE TESTING AND ASSEMBLY/DISASSEMBLY SERVICES**

As capabilities for in-space operations increase, so will the requirements for specialized in-space services. In particular, large in-space testing activities (such as those associated with developing and verification of materials applications, processing methods, testing methods, designs, structural configurations, attitude controls and station keeping, communications, energy production, fuel transfer, and robotics) will require the weightless, vacuum, and/or high radiation environment of space. They will require specialized structures, equipment, instrumentation, procedures, and personnel for operation of large central test and staging areas or "in-the-field" operations. Planning and conduct of such operations will require large coordinated efforts both on Earth and in space. Many of the technology development and test requirements will be generated by members of the private sector to support their commercial interests.

Many of the specialized and larger structures envisioned for space operation will require on-orbit assembly. There will also be continuing modifications to those previously provided structures and systems. Obsolete elements of the space stations, antennas, and other systems will require disassembly for replacement. These assembly/disassembly operations offer opportunities for involvement of the private sector in areas such as:

- 1) Development and provision of specialized tools
- 2) Training of personnel for specialized operations
- 3) In-space conduct of the operations
- 4) Support services to all of the above

Furthermore, there is a good potential for orbiting facilities to serve as an in-space test laboratory and testbeds for operations such as:

- Test and evaluation of advanced subsystems and testbeds needed for future space systems (energy storage, fluid transfer, thermal control, etc.)
- Evaluation and use of space-based solar furnaces, photovoltaic arrays and nuclear power systems
- Modal surveys and analysis of large-scale structural assemblies, masts, antennas, etc. (not feasible on surface due to size, gravity effects, etc.)
- Long-term duration testing of materials, components, and rotating machinery
- Performance evaluation of teleoperator systems and devices
- Development of procedures and equipment for in-space assembly/disassembly operations
- Large-scale thermal/vacuum testing using the readily available space environment

Such facilities, whether owned/operated by the government or the private sector, should be accessible for private sector sponsored as well as government-sponsored testing.

### **SATELLITE SERVICING**

Satellite servicing includes pre-launch and post-launch activities such as repair, refurbishment, refueling and, in some cases, reconfiguration of spares (such as Direct Broadcast System satellites, stored Low Earth Orbit for rapid deployment with the Reusable Orbital Transfer Vehicle).

The objectives of on-orbit servicing include:

- Reducing life-cycle costs
- Improving overall system reliability
- Reducing risks, particularly for larger, more complex and more costly satellites

The capability to service and repair satellites in situ or to retrieve satellites for servicing in space or on the ground should, therefore, provide lower cost, more reliable satellite payload systems. The Space Shuttle currently provides such capability for satellites in lower inclination low Earth orbits. As a result, more and more satellites are being configured to take advantage of these initial capabilities.

These capabilities, as initially provided by the Space Shuttle, will be further enhanced and extended with the advent of the Space Station, Orbital Maneuvering Vehicles, and associated teleoperators and robotics. These capabilities will be extended into highly inclined and polar low Earth orbits. With the advent of the Reusable Orbital Transfer Vehicle, these capabilities will be further extended to all Earth orbits. Furthermore, these capabilities will be increasingly enhanced with the deployment of additional Space Stations, Orbital Maneuvering Vehicles, and remotely operated hardware. Means of exploiting these capabilities will challenge the designers of satellite systems, and on-orbit operational hardware. The broad spectrum of systems that will be deployed will require a diversity of specialized skills and supporting hardware, and many types of extra-vehicular activities. These requirements will provide many opportunities for involvement of the private sector.

The Space Station will function as a way-station, providing access for servicing of satellites in non-space station orbits, and as an in-space service facility for retrieved satellites.

Potential opportunities for involvement of the private sector in the servicing of satellites include the following:

- 1) Operation of on-orbit service facilities
- 2) Provision of teleoperators, robotics, and other specialized service equipment
- 3) In situ servicing operations
- 4) Training and provision of personnel having the required specialized skills for such service operations including the required extra vehicular activities
- 5) Provision of transportation services for access to and recovery of satellites

#### **FACILITY OPERATIONS AND SUPPORT SERVICES**

This category encompasses in-space facilities for R&D activities, manufacturing, launch, docking, loading, maintenance and repair, servicing, and communications and navigation.

The initial basic Space Station will be primarily funded and owned by the government. Certain internal equipment and attached modules (and their internal equipment) may, however, be developed and owned by elements of the private sector. NASA is making every effort to assure maximum participation and support of the private sector for Space Station development and operations. As additional capabilities are added to the Space Station through attached modules, etc., there will be impetus and opportunity for private sector involvement, e.g., private sector owned and operated equipment or attached modules for materials processing labs, an in-space communications test facility, an in-space Earth and ocean sensor test facility, etc.

Ultimately, the operation of the Space Station could revert from the government to an element of the private sector. This could be accomplished under a lease arrangement or under a contract let by the government. In most likelihood, initial operations by an element of the private sector would be accomplished under the latter. As the number and capabilities of space stations increase, private ownership and/or operations under lease agreements could become more distinct probabilities.

Even with government ownership and operation of the basic Space Station, there will be many opportunities to the private sector for support services. These could include the following:

- Administrative services
- Command, control, and communications
- Data collection, analysis, and dissemination
- Instrumentation and calibration support
- Photographic services
- Facility engineering services
- Provision of energy
- Other utilities and services
- Maintenance and repair services
- Minor modification services
- Logistics support
- Extra vehicular activities
- Provisioning, maintenance, and repair of equipment and tools
- Ownership and leasing of special items of equipment and tooling
- Fuel supply
- Servicing and fueling of docked transportation systems

The many activities projected for accomplishment within or at the Space Station will require a broad range of highly specialized services which must be performed in the rigorous environment of space. These will require extensive training programs covering a variety of disciplines. Such training could well involve the private sector in the provision and operation of Earth and space-based facilities to train government and private sector personnel.

As the Space Station is established as an operational facility in space, adjacent facility elements will evolve. These will include satellite service modules; manned observatories; expanded power systems; detached test facilities; large deployed antenna; facilities for docking, fueling, servicing, and storage of space-based transportation systems; detached facilities for materials processing; facilities for processing of space debris; facilities for in-space fabrication of large structures; and (ultimately) large arrays for collection of solar energy and its conversion to RF energy for supply to ground systems.



While many of the above facilities will be owned and operated by the government for support of their continuing roles for research and development and enhancement of in-space capabilities, others may be ultimately owned and operated by the elements of the private sector as part of their commercial enterprises. Whether owned by the government or the private sector, all of these facilities will require support operations, such as identified above for the Space Station.

### **SPACE STATION DESIGN CONSIDERATIONS**

Space Station and Platform designs are inherently modular in that multiple flights of the Space Transportation System are necessary to provide the required capability. This implies a building block approach. Configurations are determined by defining and arranging modules in a manner that meets operational requirements and is compatible with the delivery system (STS). The process of defining these module functions and their arrangement in a configuration are determined by such things as: (1) The element(s) delivered on the first launch must have the capability to remain on orbit and serve as a base for additional elements (implies power, attitude control, communications capability, etc.); (2) Separation of functional activities such as habitability/operations; (3) Safety (safe haven, etc.); (4) Determination of pressurized and non-pressurized accommodations necessary (internal volume, external mounting provisions, etc.); (5) Compatibility with the Orbiter berthing and proximity operations at each stage of build-up; (6) Controllability at each stage of build-up and operation; (7) Achievement of commonality of modules where possible for cost saving considerations; (8) Compatibility with operational requirements at stages of growth and with growth to increased capability; and (9) Compatibility with cost limitations.

Studies of station concepts have led to the following element (module) functions: (1) Utility Module for power, attitude control, etc. (first launch); (2) Habitability Module; (3) Logistics Module (resupply of expendables); (4) Berthing Module; (5) Laboratory Modules; and (6) External Mission Accommodation Structure. Attitude control has been found to be a very strong driver in configuration studies due to the variations in the mass properties as the Orbiter and mission accommodation items come and go and the station evolves. These changing masses must be accommodated in such a manner that control authority requirements do not become unmanageable.

### **CONFIGURATION CONCEPTS**

Figure 6 illustrates one concept for the 75 kW station. The configuration consists basically of resource provisions (power, attitude control, communications, etc.), habitability, logistics, and mission accommodation. Mission accommodation is broken into two areas which are pressurized laboratory modules and an unpressurized area. A berthing module is used for element interfaces and contains an internal EVA airlock and controls for the station. Reboost and backup attitude control system thrusters are located in two modules as shown and are designed for orbital changeout as units. Antenna locations for this configuration have not been determined. Two locations are available for Orbiter berthing with the primary one being on the habitability module and an alternate one on the laboratory module in line with the berthing module.

Attitude control considerations were given high priority in configuring this station concept. Previous evaluation had led to the objective of creating a configuration which is balanced aerodynamically, minimizes secular torques (accumulative) and minimizes principal axis shift as large masses are added to and removed from the station. The concept which appears best to accomplish these objectives has the solar arrays located within an area centrally located between the arrays for mission and module accommodation. It is desirable to balance masses within this centrally located plane as much as possible, but compromises result in obtaining this. The configuration separates areas within this plane into a pressurized module location and an unpressurized location. This approach seems more compatible with separation of functions and allows for growth of both areas which must still occur primarily in this plane for consistency with the control approach. The Orbiter (which is a significant mass to the station) is also berthed to the station in this plane and gravity gradient effects may be used to keep the Orbiter on the Earth side to minimize control requirements.

The configuration is designed to operate in either an Earth-fixed or inertial orientation. In either case, the X-axis of the configuration is maintained perpendicular to the orbit plane and the solar arrays and radiators remain inertially fixed. For Earth-fixed capability, the central portion of the station (inboard of radiator attachment structure) rotates relative to the arrays and is Earth-fixed (axis toward Earth variable). The deployable booms for solar array positioning are provided to clear the Orbiter as it is berthed to the station and the solar arrays rotate at Earth rate relative to the Orbiter. Separate rotation capability is provided for the radiator modules so that in the Earth-fixed orientation they may remain edge-on to the Sun and be rewound on the dark side of the orbit as the solar arrays remain inertially fixed. This allows fluid transfer to the radiators by flex hoses rather than less reliable rotating seals. Another option for the radiators may be to fix them to the Resources Module without rotation capability and allow some solar illumination. This would require oversizing of the radiators. (Radiator sizing shown is consistent with no solar illumination and use of pressurized module sidewall radiators for heat dissipation.)

In order to grow beyond the 75 kW power level it is necessary to add solar array blankets, radiator elements, energy storage provision, etc. to the configuration. This would still need to be accomplished in a balanced manner with additional mission accommodation occurring in the central area. The current planning schedule for the Space Station is shown in Figure 7.

## CONCLUSIONS

What is required for space industrialization? For the answer we can look at Earth analogs. Facilities, transportation, business organization, capital, markets, and process technology are items that logically spring to mind.

Of these, several are already available for Space Industrialization. Transportation via the Space Shuttle is becoming more and more frequent and reliable. Process technology is being developed by both ground and space experiments and will become even more prolific with the advent of a permanent R&D laboratory on the Space Station. Business procedures like the current Joint Endeavor Agreements are in place now. New policies and incentives to augment and encourage business have been formulated by the NASA Space Industrialization Task Force. Now, the final key piece, a permanent base in space (Space Station), is coming to fruition. Figure 8 depicts the relationship between these various elements needed for full-scale space industrialization.

# FUNCTIONS OF SPACE STATION

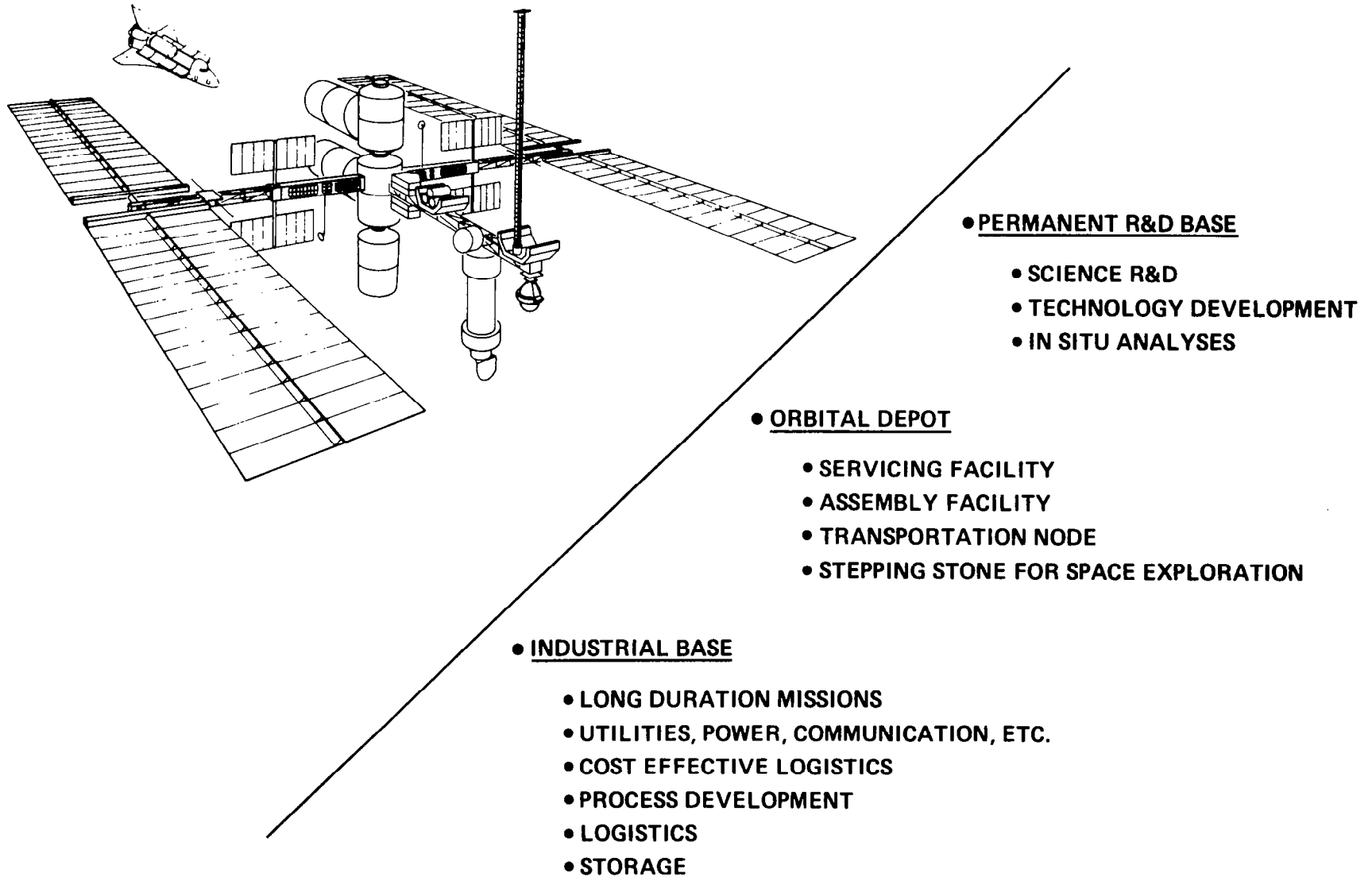


Figure 1

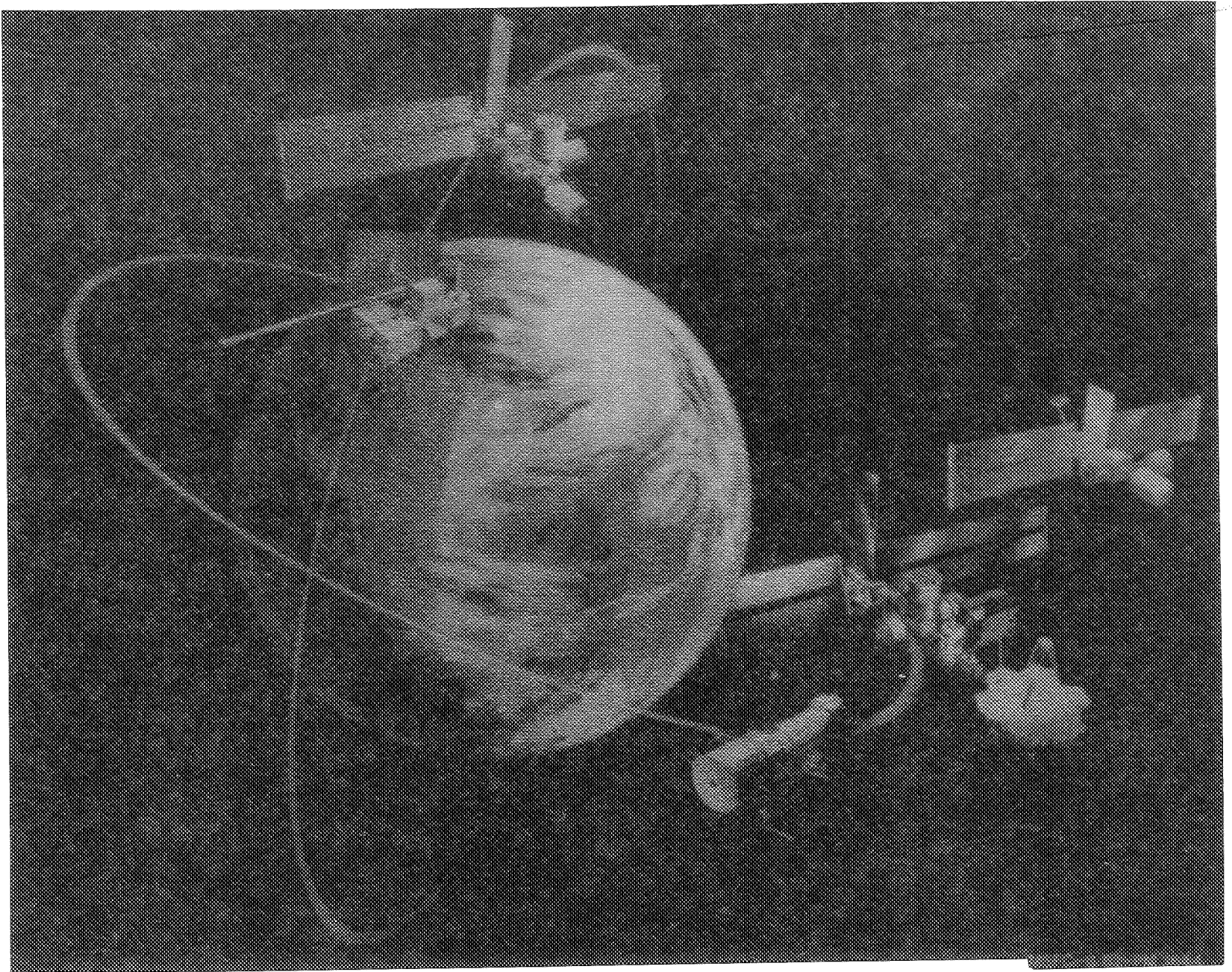


Figure 2

# GEOSYNCHRONOUS COMMUNICATIONS

## CODE-E FORECASTS

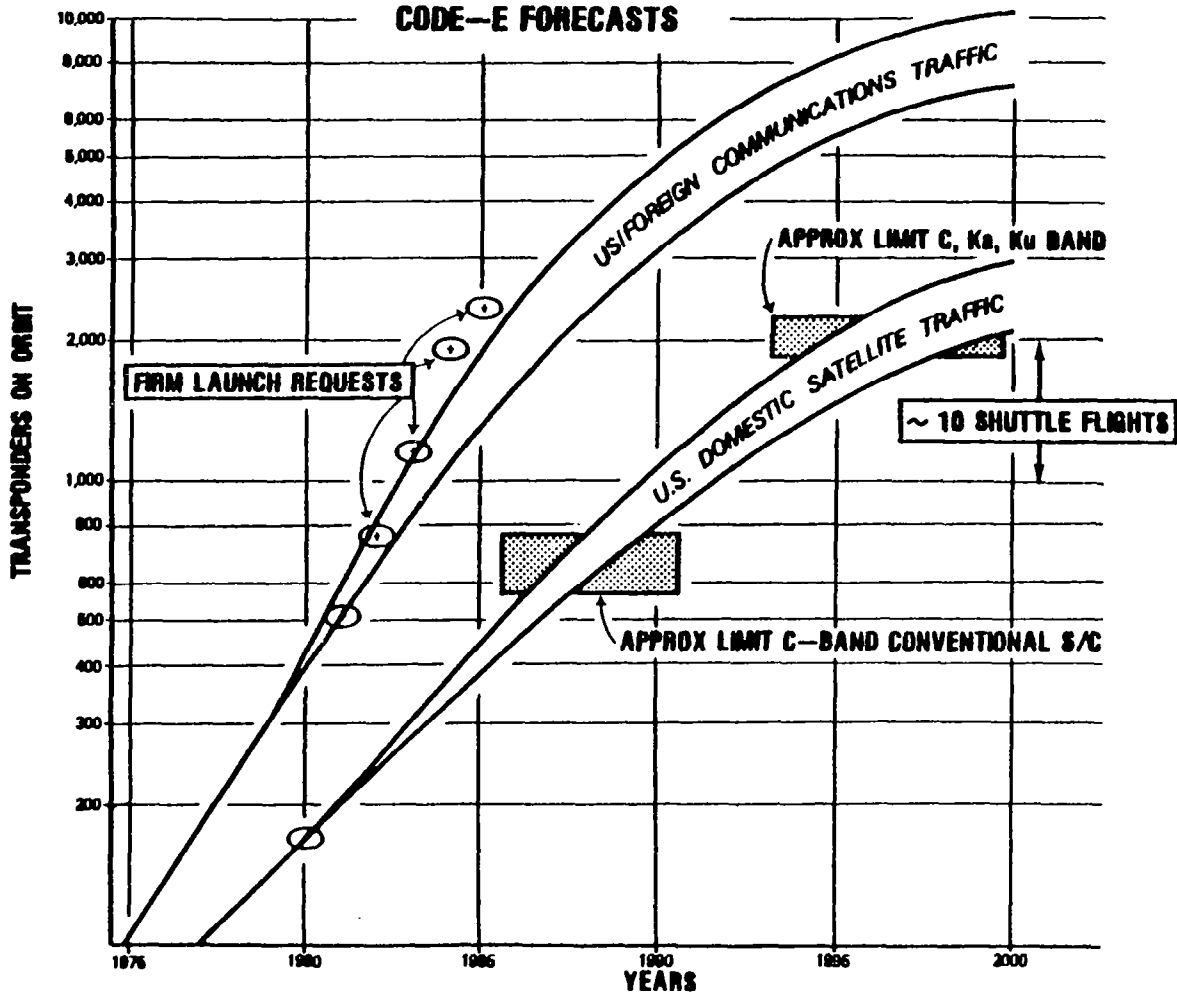
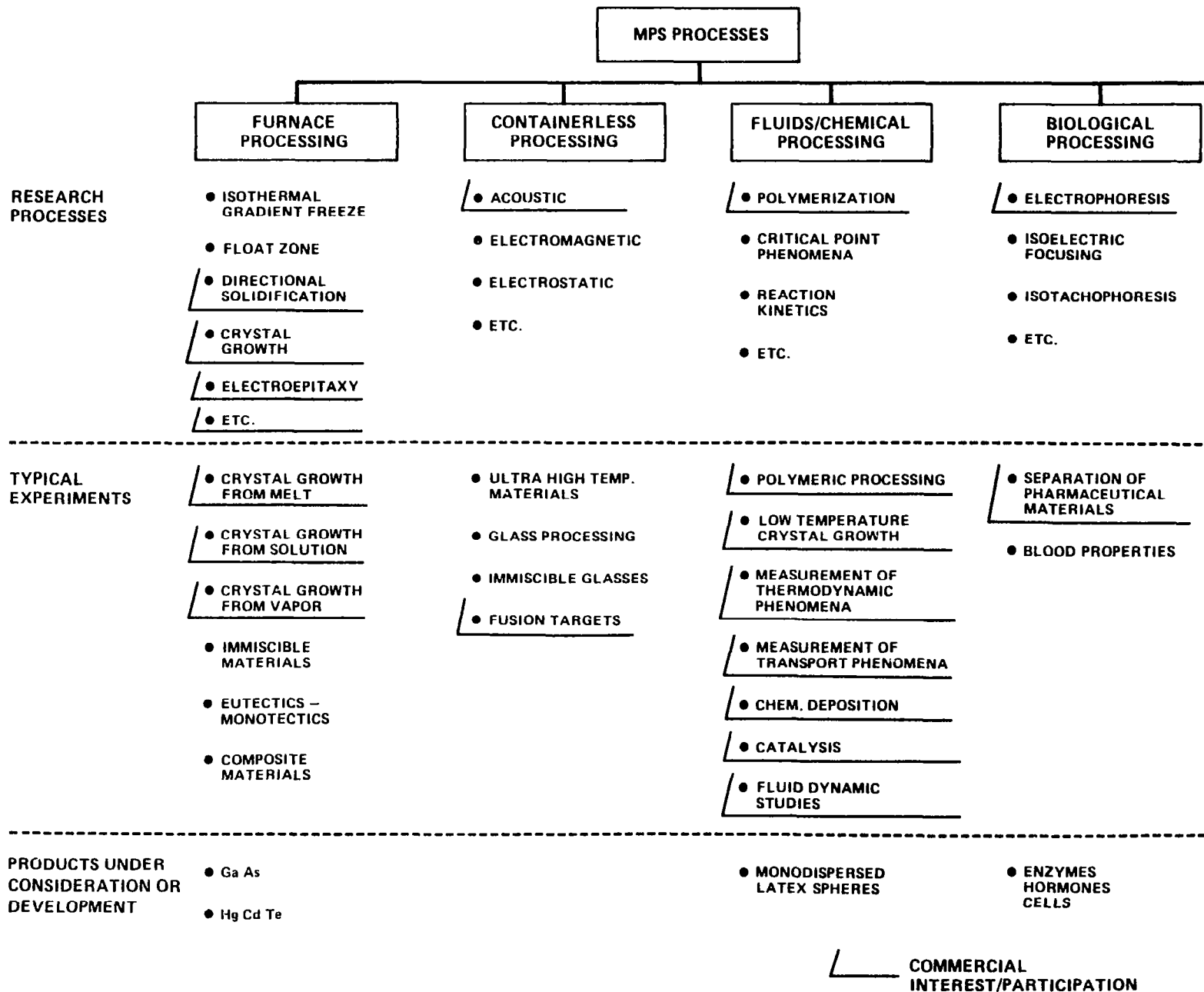


Figure 3

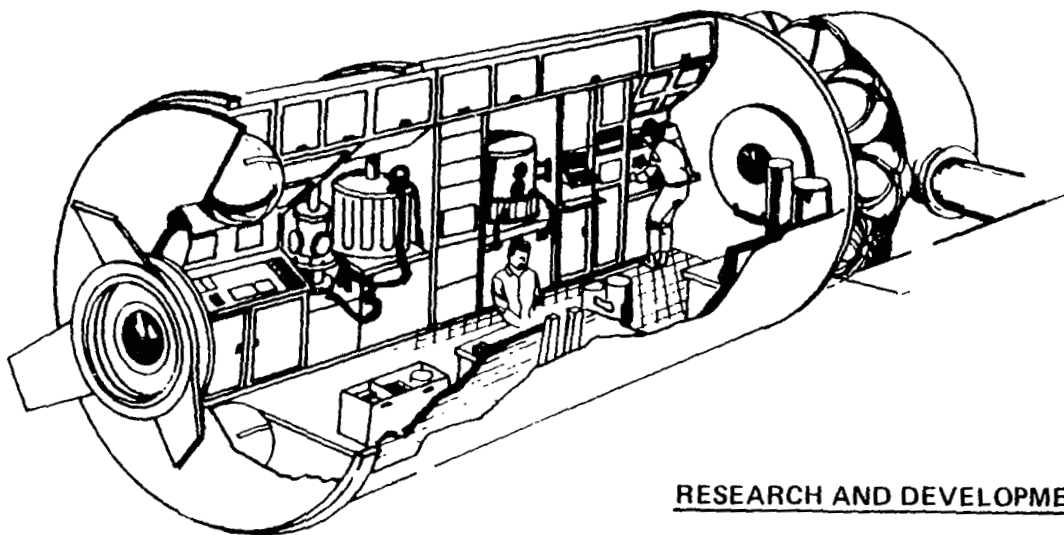
# COMMERCIAL MPS PROCESSES AND POTENTIAL APPLICATIONS



— COMMERCIAL INTEREST/PARTICIPATION

Figure 4

## MICROGRAVITY MATERIALS R&D MODULE



### RESEARCH AND DEVELOPMENT STUDIES

- CRYSTAL GROWTH
- ALLOY SOLIDIFICATION
- BIOLOGICAL SEPARATION
- UNIQUE GLASS COMPOSITION
- FLUID AND CHEMICAL PROCESSES

**Figure 5**

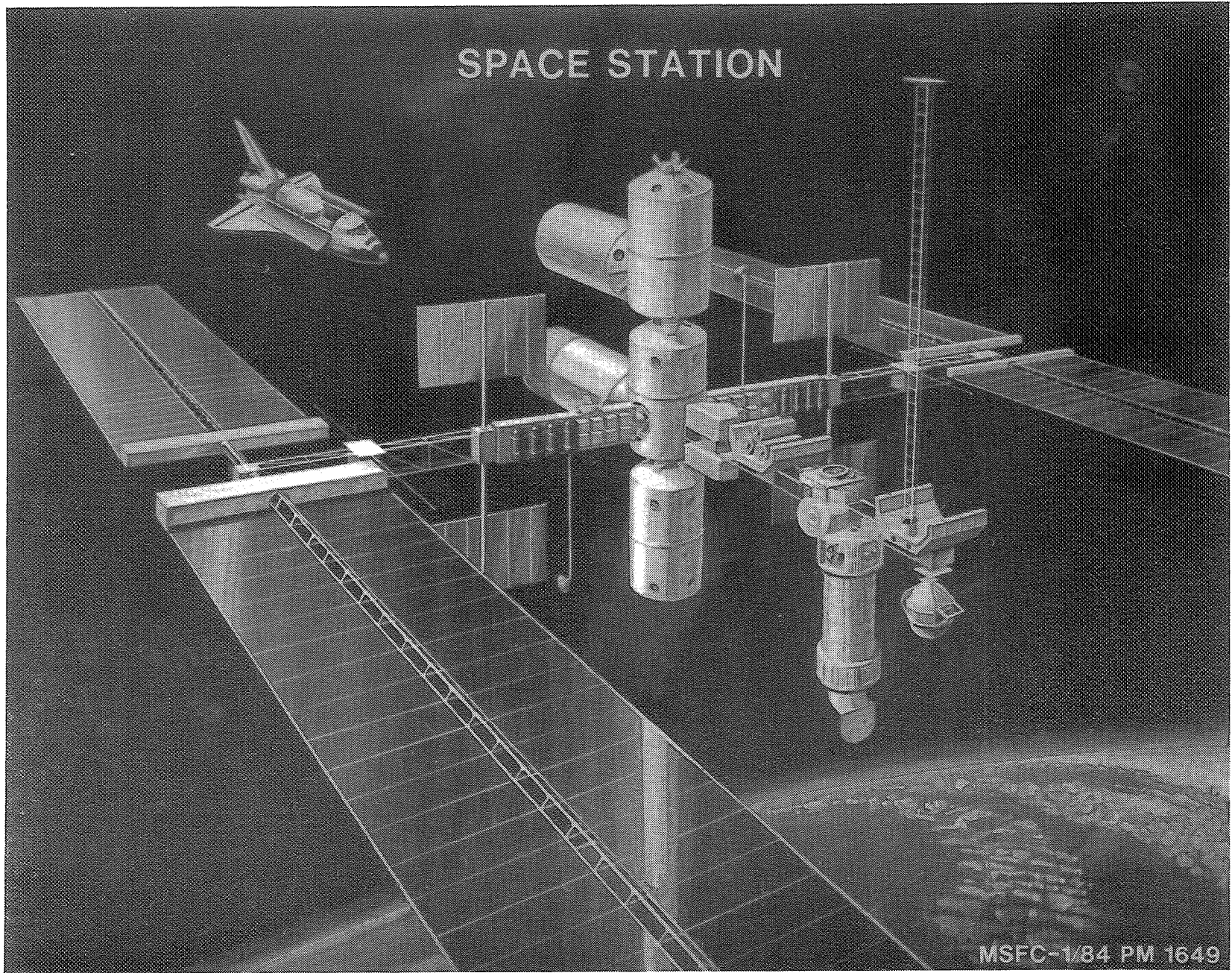


Figure 6



## SPACE STATION PLANNING SCHEDULE

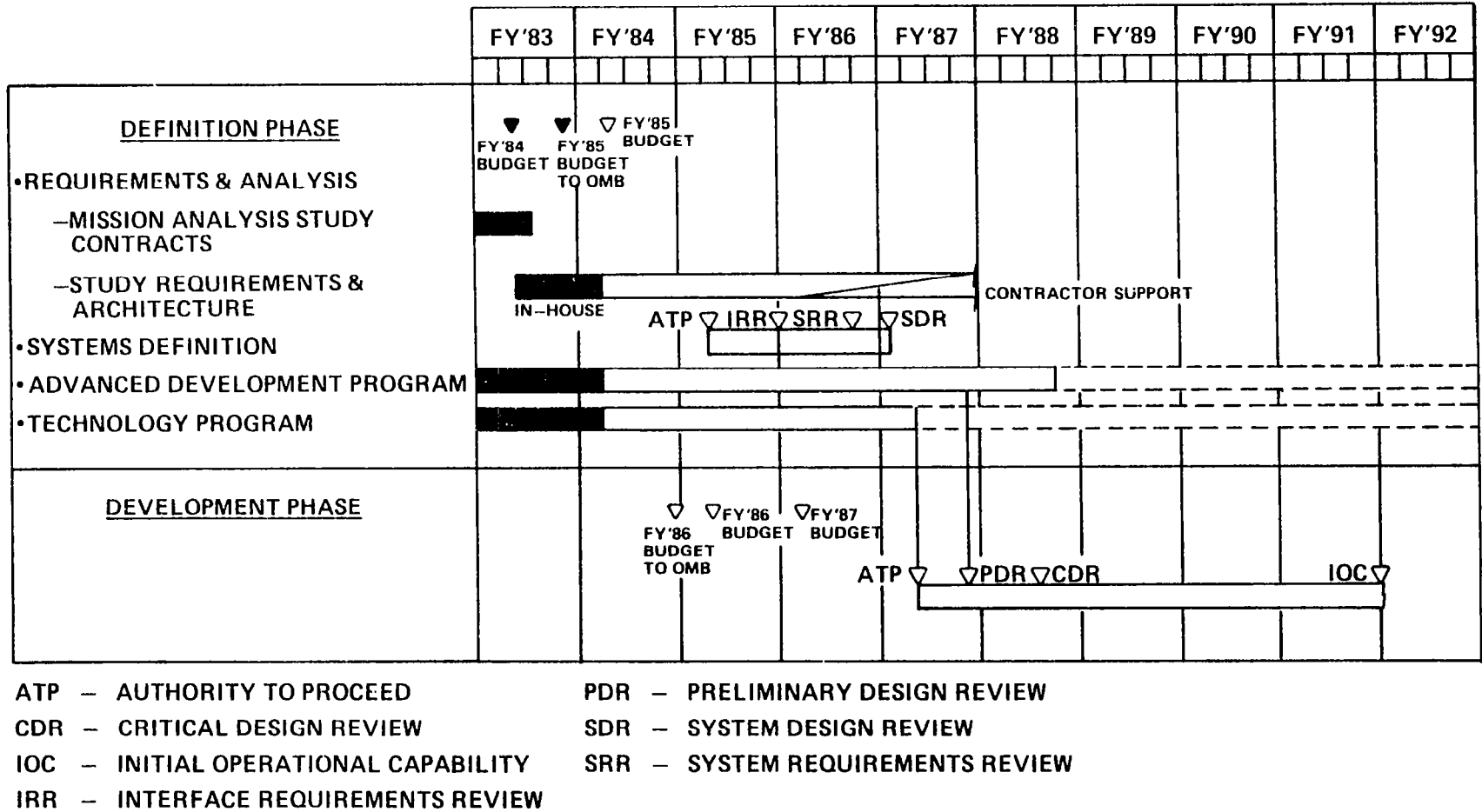
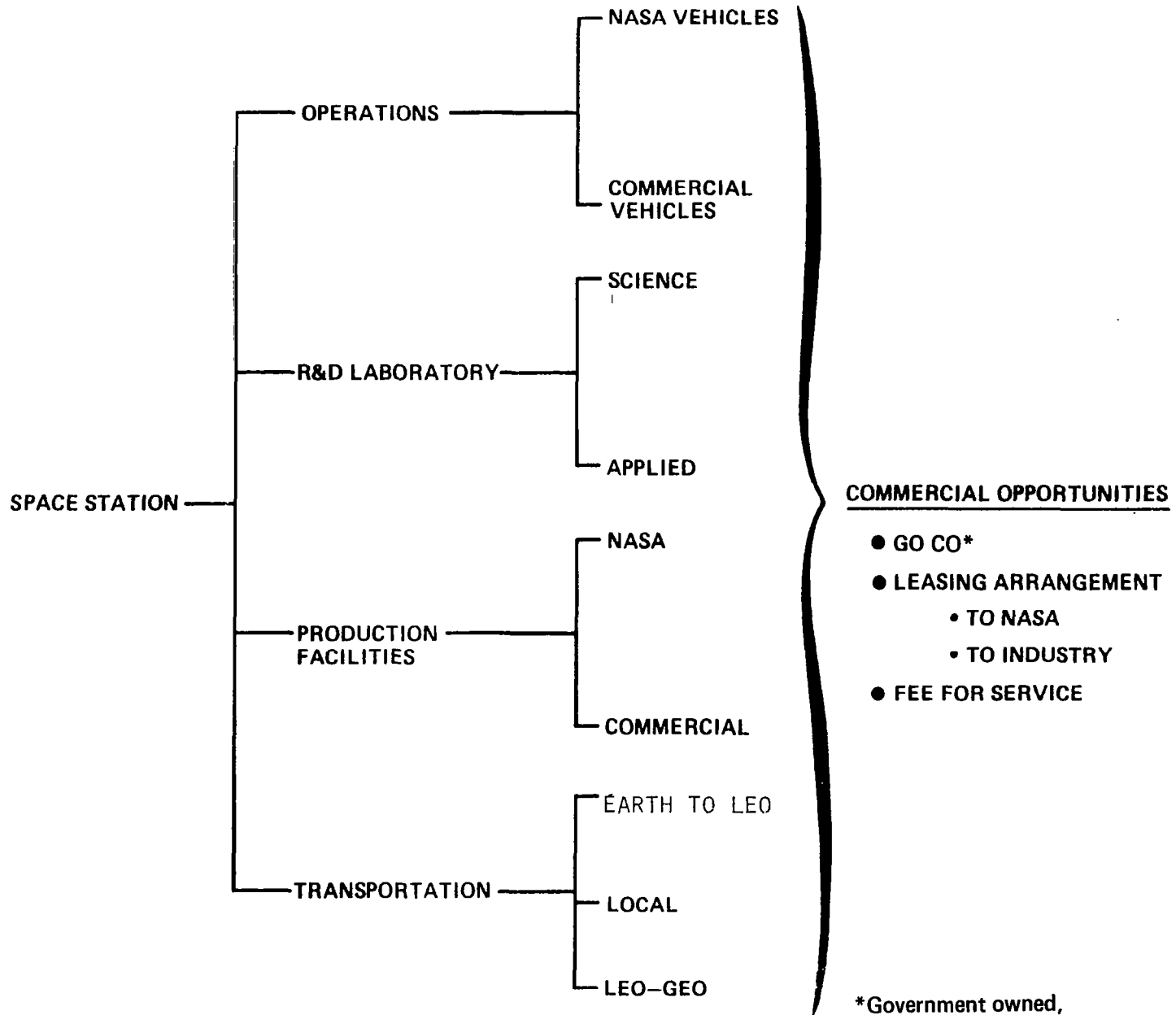


Figure 7

POTENTIAL COMMERCIAL OPPORTUNITIES IN SPACE STATION ERA



\*Government owned,  
contractor operated.

Figure 8

## POSTER SESSION

### FOREWORD

Technical Societies have begun to use poster paper sessions as an innovative method of increasing the number of papers presented at symposia such as this one. A larger number of authors can be afforded the opportunity to review their work without significantly increasing the length of the symposium. Having the poster paper session in the pre-banquet period offered a relaxed atmosphere in which the authors could display their papers and engage in mutual technical exchange with attendees. This permitted a personal dialog not possible in the formal sessions where papers were read.

Twenty-four poster papers were presented covering a range of subjects relating to space industrialization. The co-chairmen of this session wish to express our appreciation to the authors for their papers and displays, all of which were a significant contribution to the overall success of the symposium.

Mr. Alfred Orillion  
Mr. Robert Pace  
Organizing Co-Chairmen

# MICROGRAVITY CONTAINERLESS PROCESSING IN LONG DROP TUBES

by

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## ABSTRACT

Extensive experience in utilizing long drop tubes for studying effects of microgravity on the solidification of alloys has been obtained. While some modifications are necessary to improve versatility, the facility has proven to be most useful.

Both an electron beam furnace and an electromagnetic levitation furnace can be used. The electron beam furnace is used with vacuum environments ( $10^{-5}$  torr) whereas the levitation furnace is presently used only in inert gas environments (above 100 torr). Experiments are best applied to refractory alloys because of the sensitivity of the detectors now being used to observe solidification. Processing of lower melting point metals and alloys simply cannot be recorded. On the other hand, expected improvements in detector sensitivity will allow experimentation with relatively low melting alloys. In such cases, solidification will occur in flight only if higher inert gas pressure is used (100 to 760 torr) to increase heat loss by convection. Under these conditions microgravity conditions no longer apply.

However, as shown by results to date, it is not microgravity as such that is important in drop tube solidification. Instead it is the containerless nature of the process that is significant, leading to large degrees of undercooling before solidification and therefore unique alloys.

## INTRODUCTION

The one hundred meter drop tube has been used to successfully drop about seventy Nb-Ge alloys. In this context, successfully means that large undercooling was obtained before solidification occurred. These experiments, in conjunction with previous work involving the 30 meter drop tube [1-4], have shown that a drop tube is a most useful facility for studying the effects of microgravity containerless processing and low gravity containerless processing on solidification.

Several different alloy compositions in the Nb-Ge system have been studied. Namely, results have been obtained on alloys with nominal compositions Nb-13 at% Ge, Nb-18 at% Ge, Nb-22 at% Ge, Nb-25 at% Ge, Nb-27 at% Ge, and Nb-37 at% Ge. Some typical results for

Nb-25 at% Ge are presented here. It is instructive, in fact necessary, to compare the drop tube results to arc cast results and to the results of "normal" rapid solidification by liquid quenching. It is necessary because ultimately the advantages and disadvantages of microgravity containerless processing on earth as well as materials processing in space must stand against the more commonplace methods of solidification.

## DROP TUBE HARDWARE

The drop tube can accommodate any furnace that can be adapted to the bell-jar atop the facility. To date two furnaces have been successfully used to heat, melt and release samples into the drop tube for processing.

The electron bombardment, or E-beam, furnace employs a heated tungsten filament which emits electrons by thermionic emission. Since the filament is held at a negative 5 kV potential, the emitted electrons will bombard and heat the grounded sample. The sample is grounded through a tungsten support wire. One disadvantage of the E-beam furnace is that it must be operated in hard vacuum ( $10^{-5}$  torr) and is therefore limited to higher melting temperature alloys ( $T_m > 1600$  K) since the samples falling in vacuum are cooled solely by radiative heat loss. There is therefore not sufficient free fall time to undercool samples significantly before impact. To process lower temperature alloys at a higher cooling rate, an electromagnetic levitation furnace is used. The E-M levitator is powered by a 10 kW Lepel unit operating at 100 KHz. For both furnaces, the sample thermal history is recorded by an optical pyrometer before sample release into the drop tube.

Infrared detectors are used to monitor drop brightness and to sense recalescence events. Three United Detector Technology UDT450 silicon detector/amplifiers are positioned at the 40 and 264 ft levels as well as the uppermost (350 ft) level as shown in Figure 1. According to specifications, the detectors are sensitive to light from the 9660 to 2635 K (0.3 to 1.1  $\mu\text{m}$ ) range. However, recalescence events have been detected when nucleation occurred as low as 1750 K (1.66  $\mu\text{m}$ ) in the Nb-Ge alloys. During recalescence, the heat of fusion raises the drop temperature enough so that the low wavelength end of the emitted spectrum is within the detector's sensitivity range. In practical terms this means that, with the present experimental arrangement, recalescence in metals and alloys whose equilibrium freezing points are less than 1700 K cannot be observed.

Figure 2 shows the detection of recalescence in a Nb-25 at% Ge alloy. The brightness detected is measured as a function of fall time down the tube. The sharp increase in brightness at around 1.2 seconds was due to solidification at an undercooling of 242 K (about 11% below the liquidus) and therefore recalescence. The actual temperature reached, i.e., just before recalescence, was about 1920 K.

## DROP TUBE MECHANICS

In order to gain insight into the cooling capabilities of the drop tube, calculations have been performed on several pure materials. The techniques follow those of Robinson [4] and Wallace [5]. These calculations estimate the final temperature of a liquid drop released at its melting temperature and undercooled for the entire 100 meter free fall. Assuming a spherical shape, the heat loss can be expressed as [6]

$$dQ/dt = - \epsilon A \sigma (T^4 - T_0^4) - hA(T - T_0) \quad (1)$$

where  $dQ/dt$  is the time rate of heat loss,  $\epsilon$  is the emissivity of the sample,  $A$  is the area of the spherical drop,  $\sigma$  is the Stefan-Boltzmann constant,  $h$  is the convective heat transfer coefficient,  $T$  is drop temperature and  $T_0$  the ambient temperature.

Determination of the temperature requires a knowledge of the specific heat of an undercooled liquid metal. The heat capacity of undercooled metals has been found in some cases to rise continuously [7] but data are unavailable for most materials of interest. For the purpose of these calculations the heat capacity was assumed constant and equal to the liquid heat capacity of the melting temperature. Nucleation and growth of the solid phase will terminate the undercooling of the materials before the limit of undercooling in the drop tube is reached. The calculations reflect the maximum undercooling possible in the absence of solidification.

The three masses used in the calculations represent the limit of sizes possible with present drop tube furnaces. Masses from 0.070 to 0.140 grams have been dropped from the E-beam furnace in vacuum conditions. Electromagnetic levitated samples from 0.2 to 0.5 grams have been successfully dropped in helium atmospheres. In vacuum conditions  $h$  is zero and cooling is accomplished by radiation alone. Since the temperature dependence of the emissive term in equation one is to the fourth power, it is not surprising that lower melting point materials will undercool very little in vacuum. Inert atmospheres of increasing pressure increase the importance of the convective term, the second term of equation one, and allow large undercooling in lower melting metals.

Undercooling has been normalized to the hypercooling temperature. Calculations of heat flow in solidifying drops have shown that for conditions similar to the drop tube ( $h \leq 10^3$  K/sec, Biot number  $< 0.1$ ) the solidifying interface will recalesce to the melting temperature unless the hypercooled regime is achieved [8]. The hypercooling temperature for the pure metals considered has been estimated as (after Hirth) [9]:

$$T^* = \Delta H/C_p \quad (2)$$

where  $\Delta H_f$  is the heat of fusion at the usual freezing point ( $T_m$ ) and  $C_p$  is the heat capacity for the liquid metal. Table 1 lists the calculated hypercooling temperatures.

The results of the calculations for vacuum, 200 torr He, and 760 torr He are shown graphically in Figures 3, 4 and 5 respectively. Note that in vacuum only metals and alloys whose freezing points are above 2000 K can be hypercooled and even then only if the drop mass is about 70 milligrams. At 200 torr the hypercooling can be achieved with metals whose melting point is about 900 K as long as the drop mass is less than 200 milligrams. With 760 torr He there is no problem with hypercooling low melting metals and alloys even with drop sizes as large as 500 milligrams.

The above results show that it would be necessary in some cases to use an atmosphere in the drop tube in order to obtain significant undercooling before impact at the bottom. Hence, it would obviously be required to know the drag force on the drops in such experiments.

The drag force on drops was calculated for Nb-27 at% Ge drops of three different masses at helium pressures from 100 to 800 torr and expressed as a fraction of earth gravity. Spherical liquid drops were assumed to be released at the melting temperature and allowed to undercool for 100 meters. At the end of free fall the velocity, Reynolds number and gas properties were noted. The drag coefficient was determined from White's empirical curve fit for spheres [11],

$$C_D = 24/Re + 6/(1+R3) + 0.4 \quad (3)$$

where  $C_D$  = drag coefficient and  $Re$  is the Reynolds number. The drag coefficient is then used according to the method of Incropera and DeWitt [12] to determine the drag force as:

$$F_D = C_D A \rho V^2 / 4 \quad (4)$$

where  $F_D$  is the drag force,  $A$  is the area normal to the free stream,  $\rho$  is the density of the gas at the thin film temperature, and  $V$  is the velocity of the drop. The radii of the drops are: 0.2 grams = 1.8 mm, 0.5 grams = 2.5 mm, 5 grams = 5.4 mm. The drag forces as a function of size and pressure are shown in Figure 6.

## EXPERIMENTAL RESULTS

Deep undercooling has been obtained in a variety of Nb-Ge alloys. A summary of the undercooling is given in Figure 7; the temperatures at which recalescence was observed to occur are superimposed on the Nb-rich portion of the Nb-Ge phase diagram. Undercoolings ranged from 3% and 6% (about 40 K and 100 K respectively below the liquidus) in two separate Nb-25 at% Ge specimens to 31% (about 760 K) below the liquidus in a Nb-16 at% Ge specimen. A number of specimens, each of different Ge composition, undercooled to about 25% of the liquidus but the most common experience was for undercooling to about 20% of the liquidus.

Microstructural analysis by x-ray diffraction, optical microscopy, and scanning electron microscopy with energy dispersive analysis has been done in each case. Some results for Nb-25 at% Ge specimens in the as-dropped undercooled condition are presented below and compared to specimens in the arc cast condition and the liquid quenched condition.

### Arc Cast Nb-25 at% Ge

Arc cast on a water cooled copper block, this alloy has a matrix of  $\gamma$  particles (35 at% Ge) having a bimodal size distribution, which are surrounded by a continuous  $\beta$  phase (19.8 at% Ge). By volume, the matrix is 64%  $\beta$ , 33% large ( $38.8 \mu\text{m} \times 9.4 \mu\text{m}$ )  $\gamma$  particles, and 3% small ( $5.4 \mu\text{m} \times 3.7 \mu\text{m}$ )  $\gamma$  particles. This alloy is shown in Figure 8.

### Drop Specimen NT008

This specimen was melted in the electron-beam furnace, dropped in a vacuum ( $10^{-5}$  torr), and quenched in oil. It has an actual composition of Nb-26.5 at% Ge. The specimen undercooled 450 K ( $\Delta T/T_m = 0.22$ ).

Shown in Figure 9, approximately 77% of this specimen consists of finely dispersed  $\gamma$  particles (35 at% Ge) in a continuous  $\beta$  phase (22 at% Ge). Here, these regions appear dark.

By volume, these particles comprise 41% of the fine regions and are approximately  $4.6 \mu\text{m} \times 1.5 \mu\text{m}$  in size. A higher magnification of a fine region is shown in Figure 10.

The remaining 23% of the specimen has a coarsened structure, appearing as the light regions in Figure 9. These regions have enlarged  $\gamma$  particles (36.4 at% Ge,  $13.8 \mu\text{m} \times 3.6 \mu\text{m}$ ) in a continuous  $\beta$  phase (20.5 at% Ge). These particles comprise 31% of the coarsened regions. It is thought that the coarsening is caused by localized reduced solidification rates due to recalescence effects.

#### Drop Specimen NT146

This specimen was melted in the levitation furnace, dropped in an atmosphere of 200 torr of helium, and gas quenched as it fell down the tube following recalescence. It has an actual composition of 25.3 at% Ge and it undercooled 534 K ( $\Delta T/T_m = 0.25$ ).

Figure 11 shows that the specimen has regions of fine and coarsened structures similar to NT008 except that only a trace of the specimen has the coarsened structure. Also, the size of the  $\gamma$  particles as shown in Figure 12 are smaller than those of NT008. Having a bimodal size distribution, the larger particles are about  $2.8 \mu\text{m} \times 1.2 \mu\text{m}$  in size, and the smaller ones are  $0.6 \mu\text{m} \times 0.4 \mu\text{m}$  in size. Both contain between 31 and 34 at% Ge.

#### Nb-25 at% Ge Liquid Quenched

Shown in Figure 13, this specimen was arc melted and then sprayed on a copper block. Here very fine  $\gamma$  particles can be seen comprising 35% of the volume with the balance being a continuous  $\beta$  phase. The particles again show a bimodal distribution in size; the larger ones being  $0.4 \mu\text{m} \times 0.1 \mu\text{m}$ , and the smaller ones  $0.2 \mu\text{m} \times 0.05 \mu\text{m}$ .

### SUMMARY

Table 2 summarizes the analysis of the specimens. Each condition is unique in its own right. NT 008 having undercooled 450 K, clearly shows the effect of recalescence in that it shows regions of coarse dispersions amidst regions containing fine dispersions. The more coarsely dispersed regions have particle sizes approximately 1/3 the size of the arc cast case but the compositions of the phases are similar to the arc cast case.

NT 146 undercooled about 534 K. The extra undercooling produced a microstructure further approaching the liquid quenched case although the particle size for liquid quenching is about 15% that of the drop tube specimen. Note however that the compositions of the phases are similar.

It is interesting to observe then that deeply undercooled bulk specimens can be obtained by containerless processing that are similar morphologically to liquid quenched specimens where one is restricted to a very thin sheet as a final product. In this context it would appear that, at least in this alloy system where the density of the phases is about the same, that the principal effect of a microgravity environment would be to provide conditions where a containerless process on a large scale is relatively easy to achieve. Such a characteristic then could be a major advantage of microgravity in producing unique bulk alloys.



## REFERENCES

1. L. L. Lacy, M. B. Robinson, T. J. Rathz, N. D. Evans and R. J. Bayuzick, in "Materials Processing in the Reduced Gravity Environment of Space," edited by G. E. Rindone (Elsevier Science Publishing Co., New York, 1982), p. 87.
2. L. L. Lacy, T. J. Rathz, and M. B. Robinson, *J. Appl. Phys.* 53, 682 (1982).
3. L. L. Lacy, M. B. Robinson, and T. J. Rathz, *J. Cryst. Growth* 51, 47 (1981).
4. M. B. Robinson, M. S. Thesis, University of Alabama in Huntsville, 1981; NASA Report TM-82423, May 1981.
5. D. B. Wallace, Report on NASA/ASEE Summer Faculty Research Program, 1981.
6. Zemansky, M. W., Heat and Thermodynamics, 5th Edition (McGraw-Hill Book Co., New York, 1968).
7. J. H. Perepezko and D. H. Rasmussen, *Met Trans* 9A, 1490 (1978).
8. R. Mehrabian, *Intl. Metals Reviews*, 27, 185 (1982).
9. J. P. Hirth, *Met. Trans.* 9A, 401 (1978).
10. "Handbook of Tables for Applied Engineering Science, 2nd Edition", edited by R. E. Bolz and G. L. Ture (CRC Press, Cleveland, Ohio, 1973).
11. F. M. White, "Viscous Fluid Flow" (McGraw-Hill Book Co., New York, 1974) p. 209.
12. F. P. Incropera and D. P. DeWitt, "Fundamentals of Heat Transfer" (John Wiley & Sons, New York, 1981) p. 342.

TABLE 1

## Hypercooling Temperatures for Selected Metals

Element	$T_m$ (K)	$\Delta H$ (J/mole)	$T^*$ (K)	$T^*/T_m$
Al	933	10,669	364	0.39
Cu	1356	13,453	429	0.32
Ni	1726	18,128	471	0.27
Fe	1808	15,305	366	0.20
Pt	2045	21,957	583	0.28
Nb	2741	26,822	664	0.24

$T_m$ ,  $\Delta H$ ,  $C_p$  from CRC Handbook<sup>10</sup>

TABLE 2

## Quantitative Analysis of Nb-Ge Alloys

Specimen Type	$\beta$ Composition at% Ge	$\gamma$ Composition at% Ge	v/o $\gamma$	$\gamma$ Size $\mu\text{m}$
Arc Cast	19.8	35.0	33 3	38.8 x 9.4 5.4 x 3.7
NT 008A(1)	22.0	35.0	41	4.6 x 1.5
NT 008B	20.5	36.4	31	13.8 x 3.6
NT 146	21.3 to 24.5	3.1 to 34.1	30	2.8 x 1.2 0.6 x 0.4
Liquid Quenched	23(2)	30.5 to 32.0(2)	34	0.4 x 0.1 0.2 x 0.05

1. A corresponds to the dark regions in Figure 9. B corresponds to the light regions.
2. Because of the extremely fine structure these compositions are only nominal. Accurate determinations will eventually be made by use of analytical transmission electron microscopy.

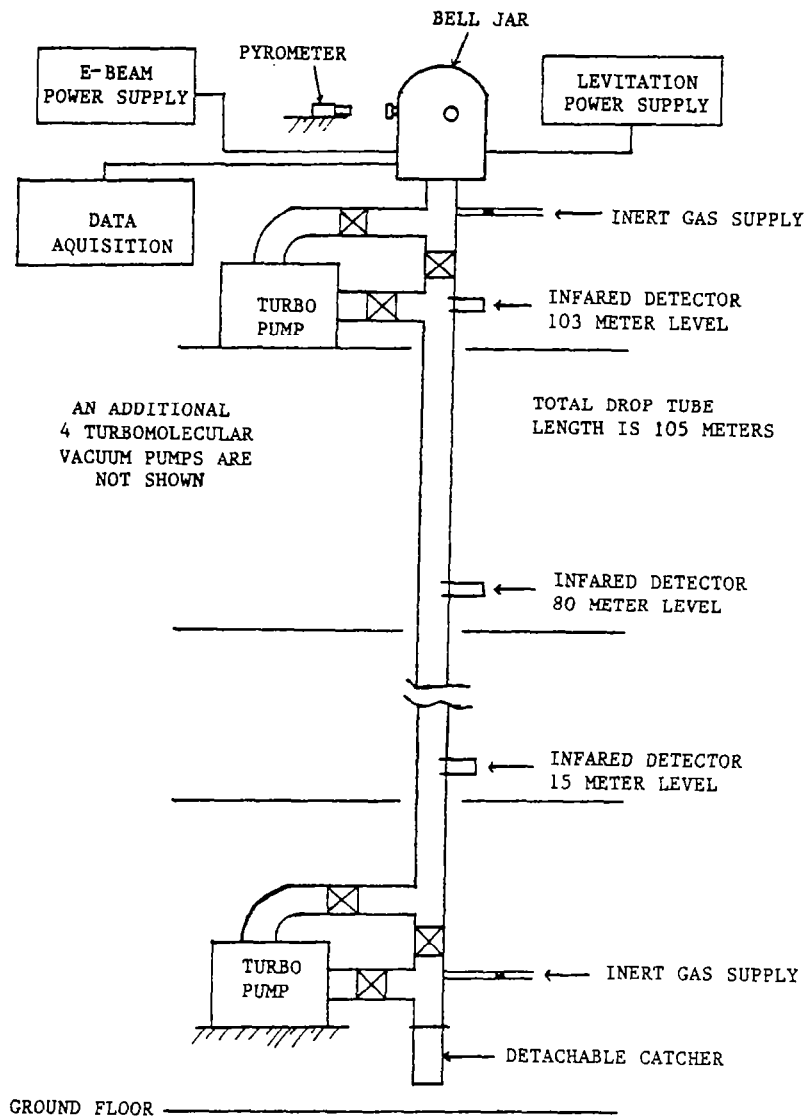


Figure 1. The 100 meter drop tube.

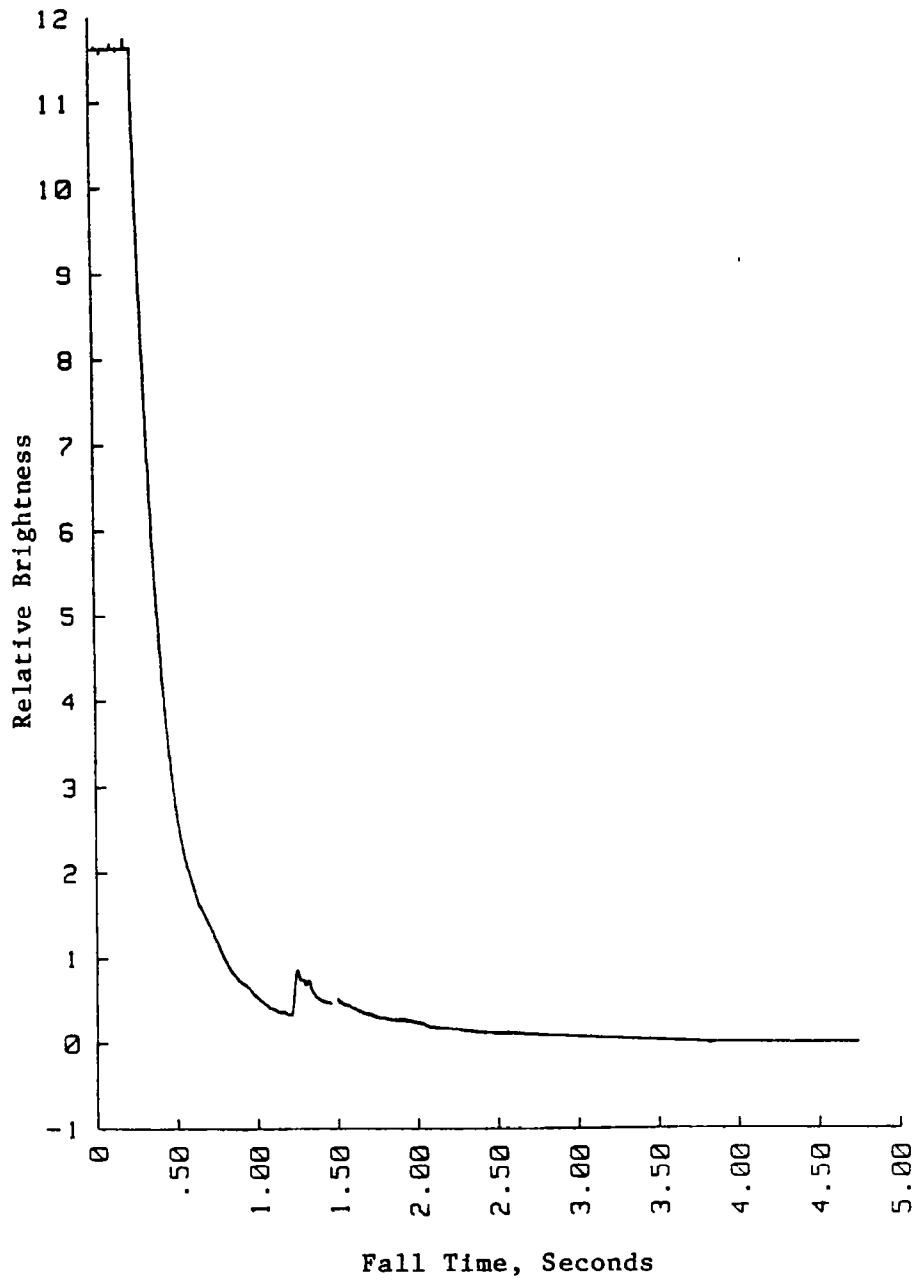


Figure 2. Example of a brightness curve for a Nb-Ge specimen.

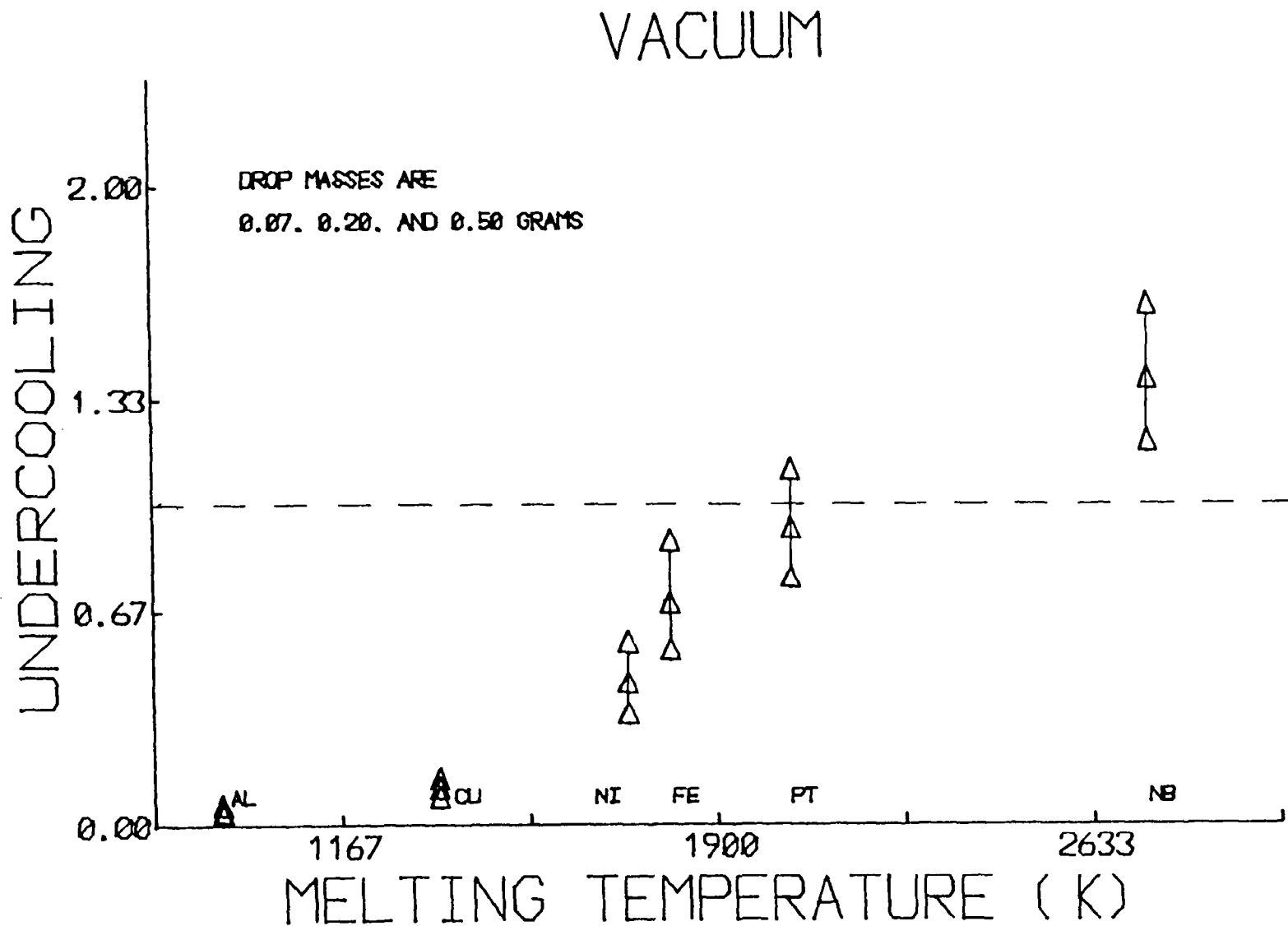


Figure 3. Maximum possible undercooling in vacuum for selected metals in the 100 meter drop tube.

# 200 TORR HE

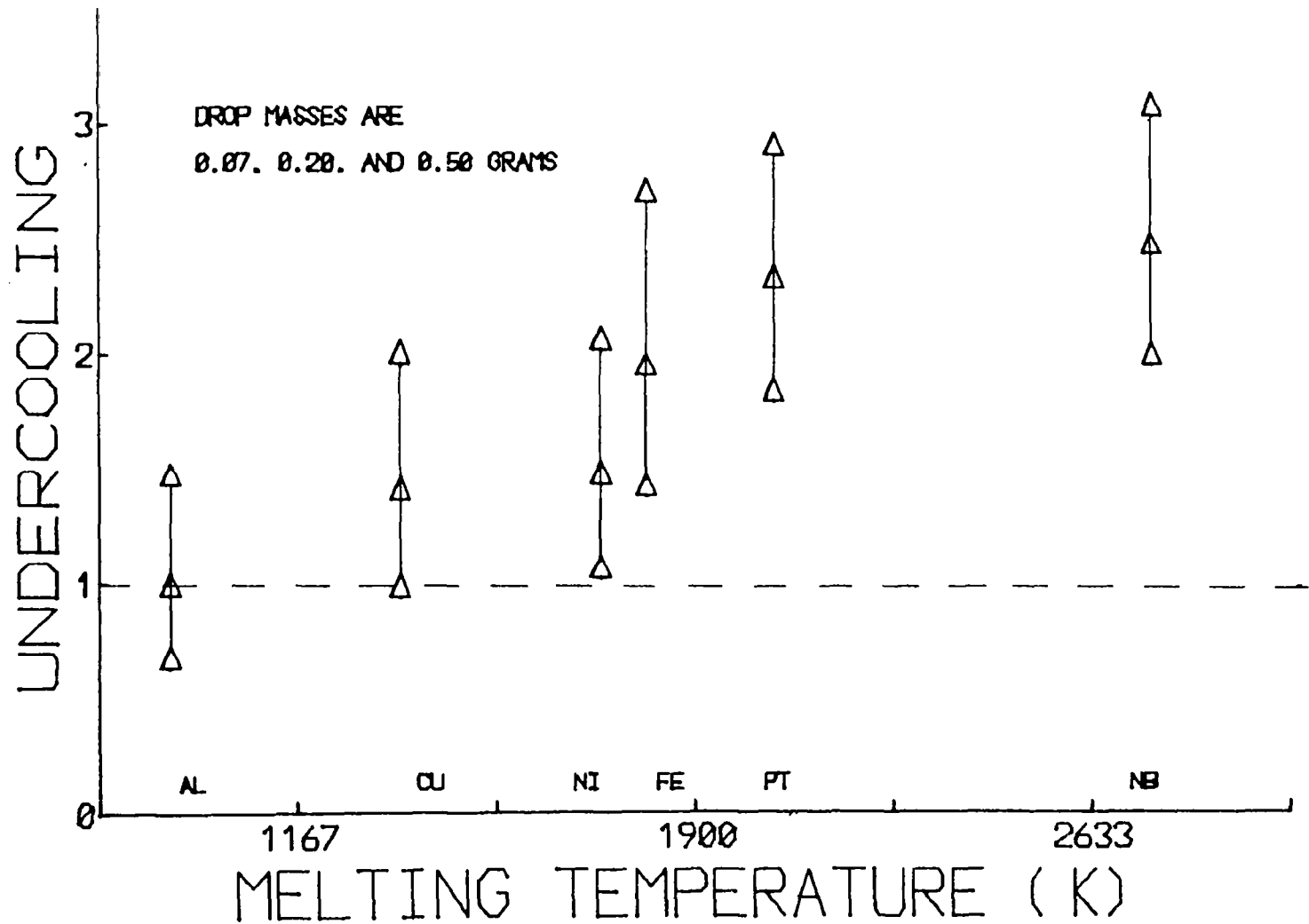


Figure 4. Maximum possible undercooling in 200 torr He for selected metals in the 100 meter drop tube.

## 760 TORR HE

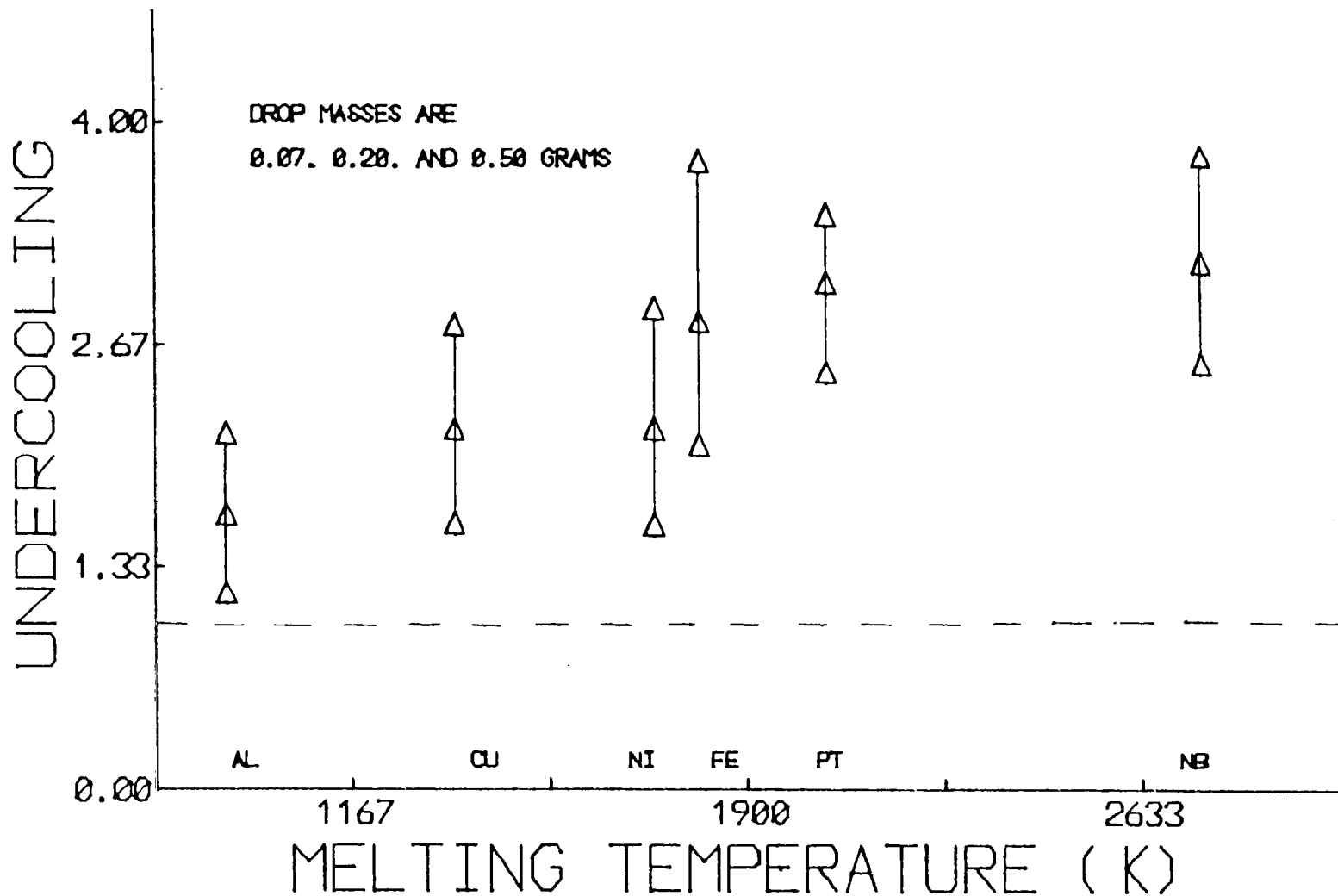


Figure 5. Maximum possible undercooling in 760 torr He for selected metals in the 100 meter drop tube.

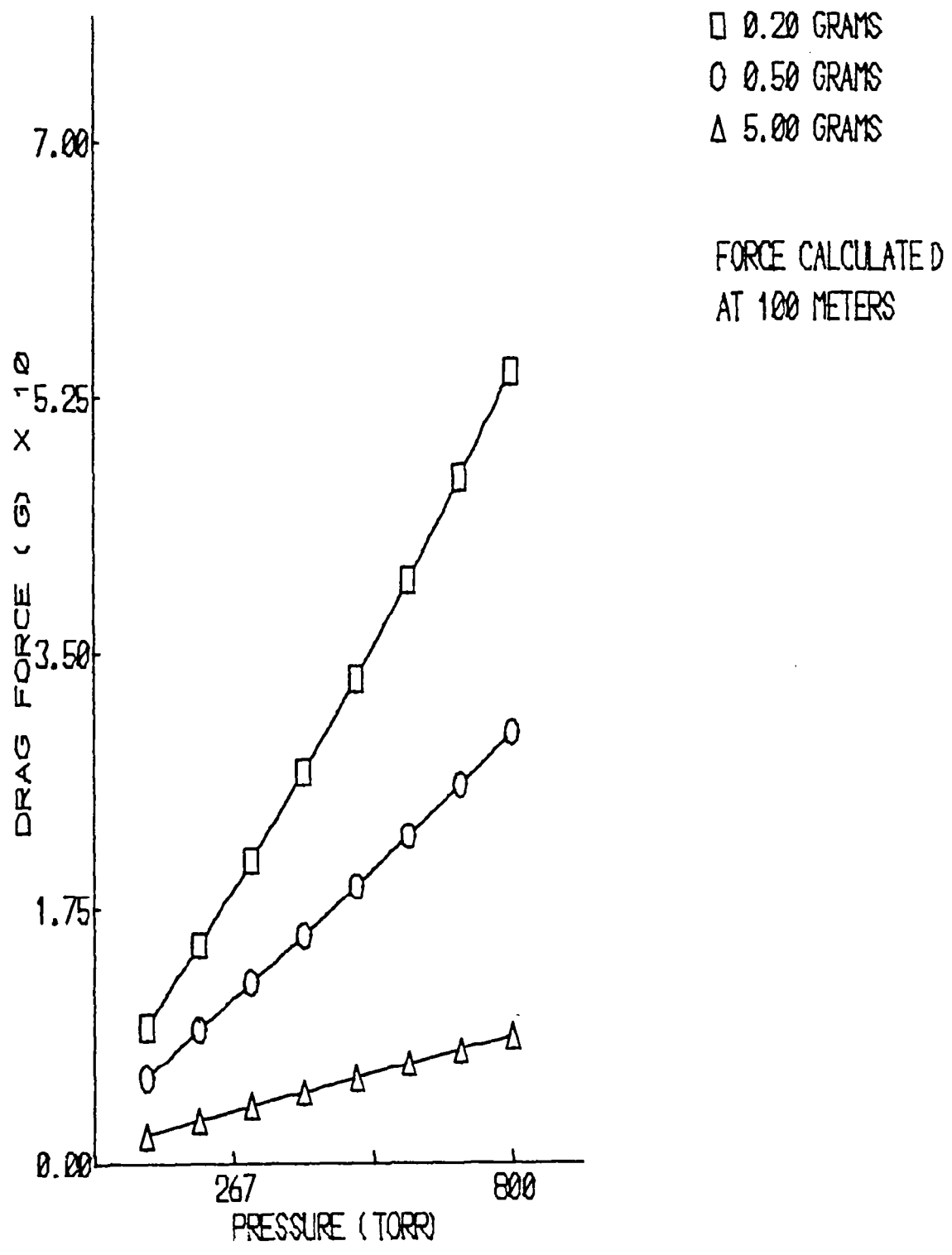


Figure 6. Drag force on various size Nb-27 at% Ge drops.



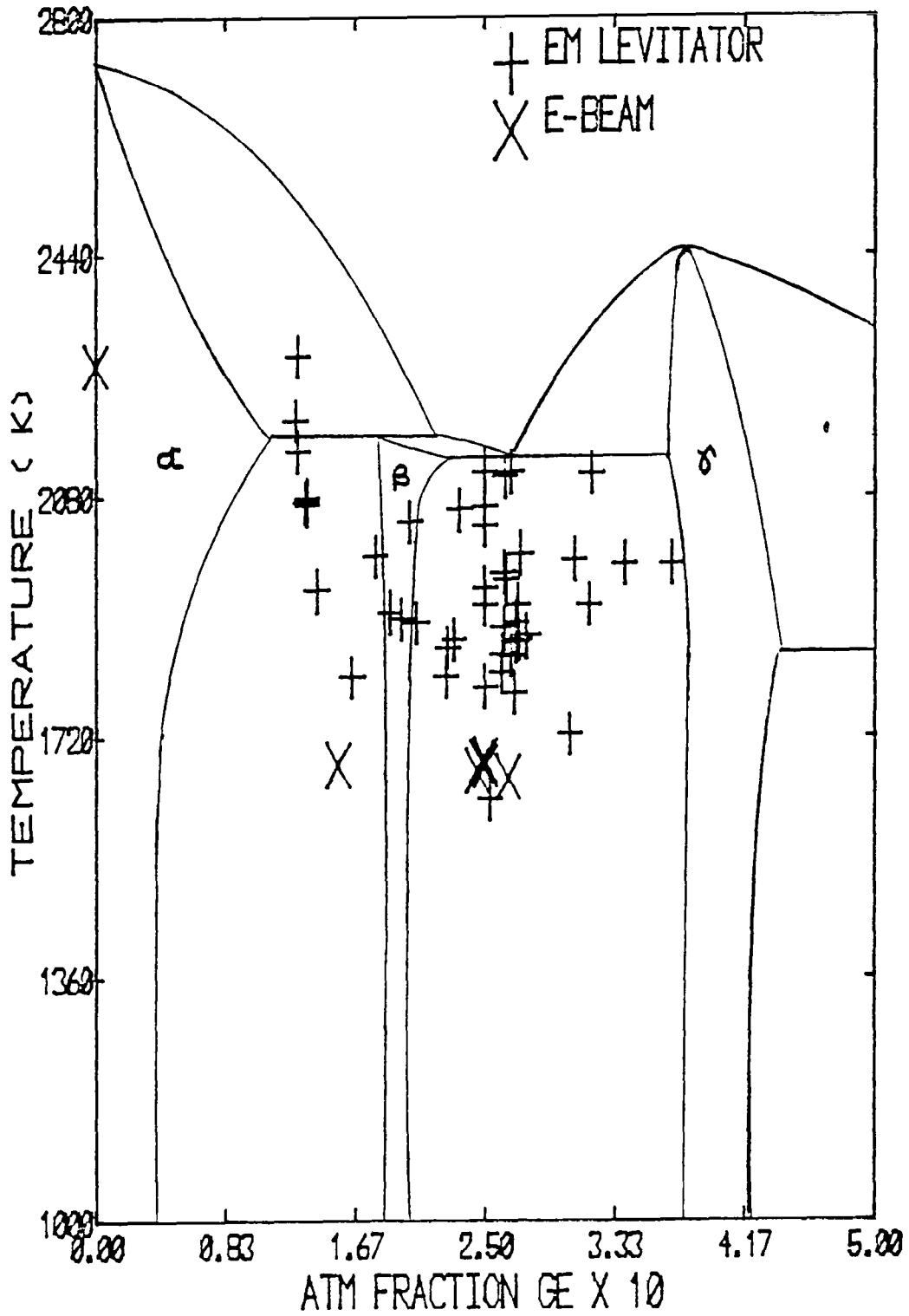


Figure 7. Summary of undercooling experience with the Nb-Ge binary system.

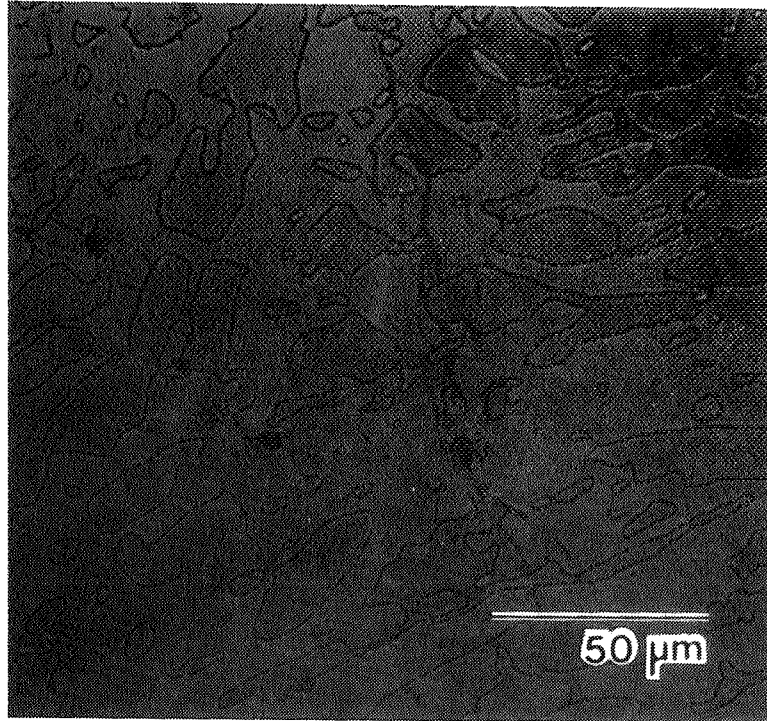


Figure 8. Arc cast microstructure of Nb-25 at% Ge.

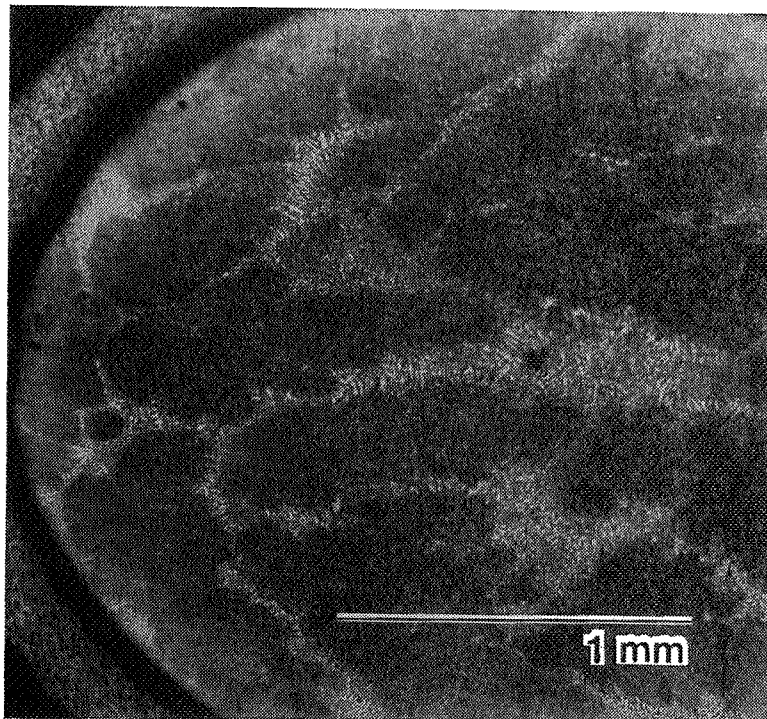


Figure 9. Micrograph of NT 008 where undercooling was 450 K.

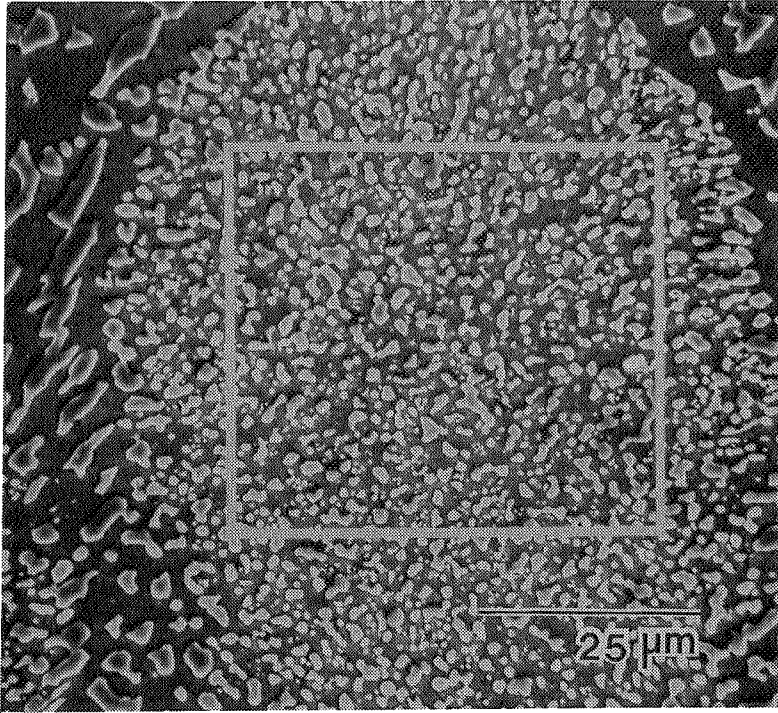


Figure 10. Microstructure of the fine regions in NT 008.

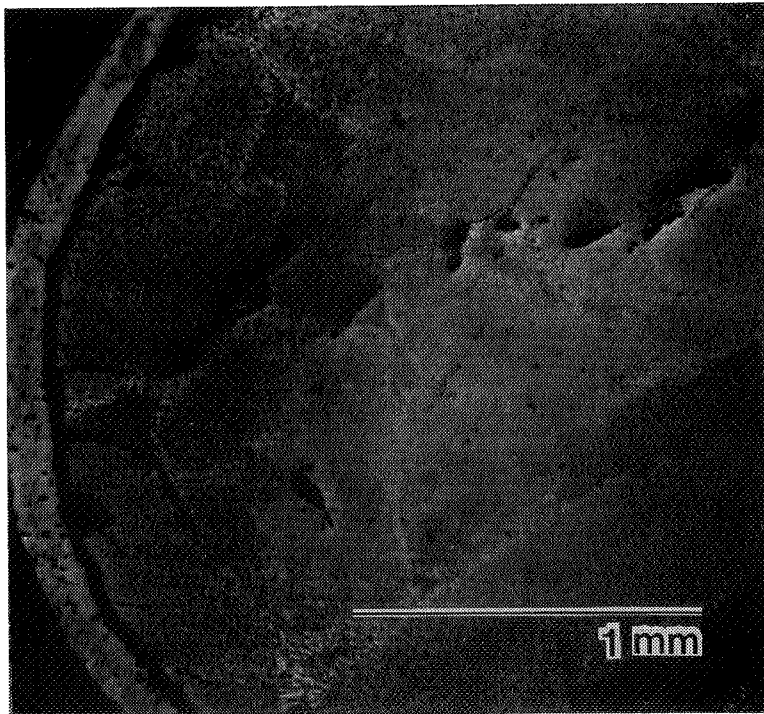


Figure 11. Macrograph of NT 146 where undercooling was 534 K.

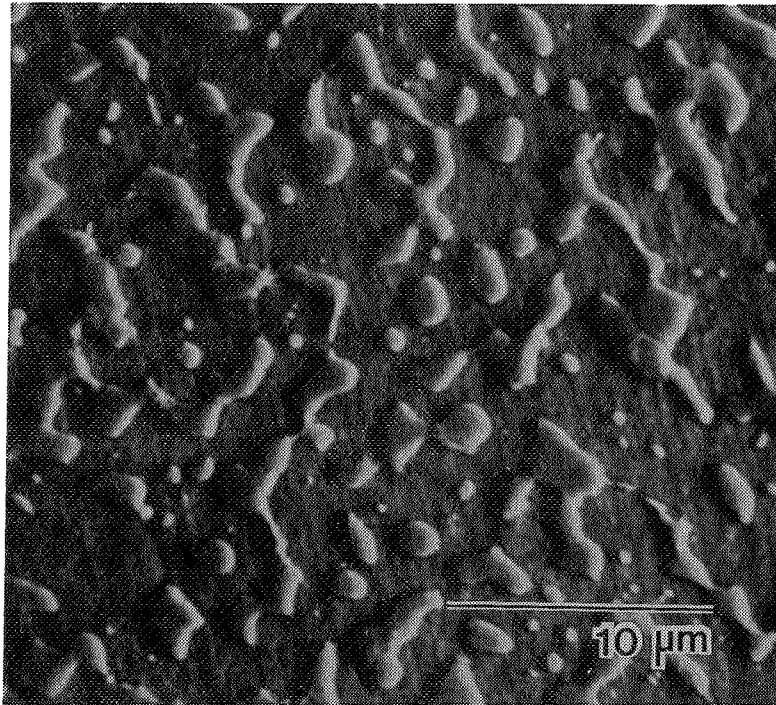


Figure 12. Microstructure of the fine regions in NT 146.

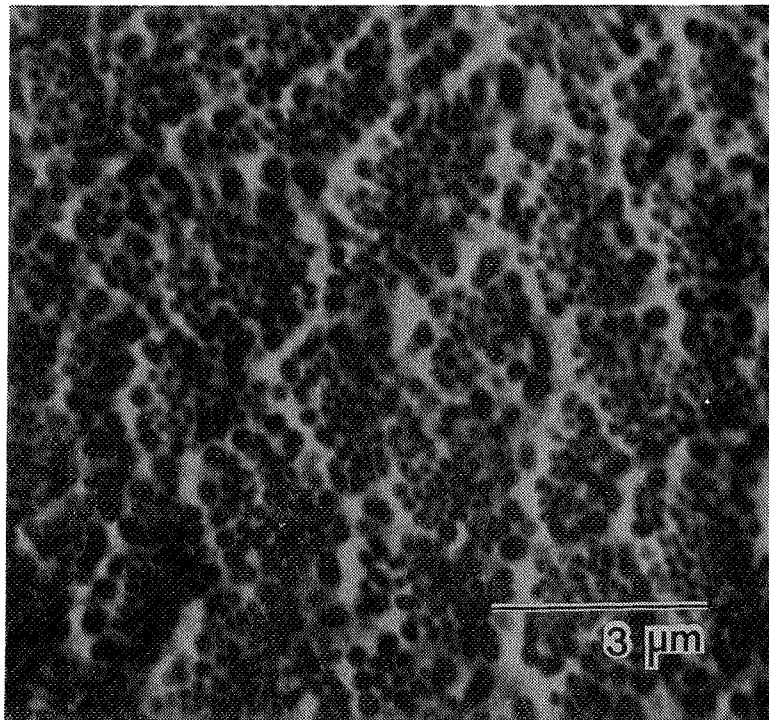


Figure 13. Microstructure of liquid quenched Nb-25 at% Ge.

# THE EVOLUTION OF SMALL PAYLOAD CARRIER SYSTEMS

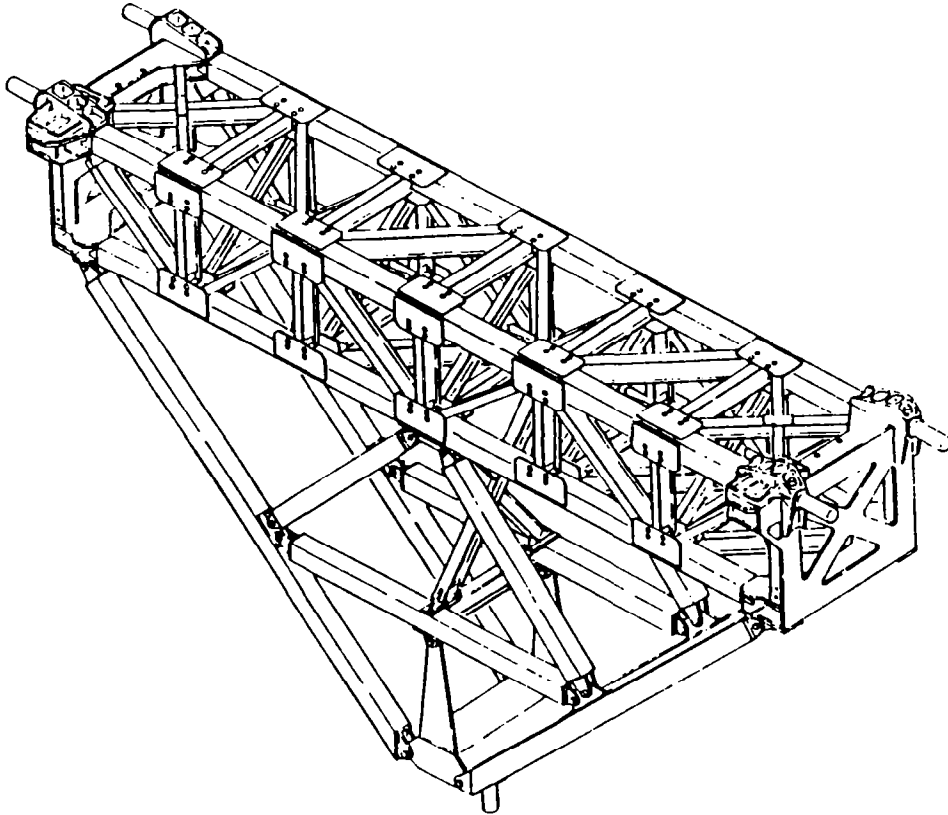
by

C. G. Breaux  
Teledyne Brown Engineering  
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## IN THE BEGINNING . . . MPES

The need for a special structure for small Shuttle payloads began to emerge in October 1978 during the development of the design requirements for two material science experiments. In contrast to a dedicated Spacelab Mission this payload was to occupy only part of the Orbiter cargo bay.

These requirements led to the design of a bridge-like structure which would span the cargo bay but occupy only 3 feet of its length. The new structure was named the "Missions Peculiar Equipment Support Structure" (MPES).



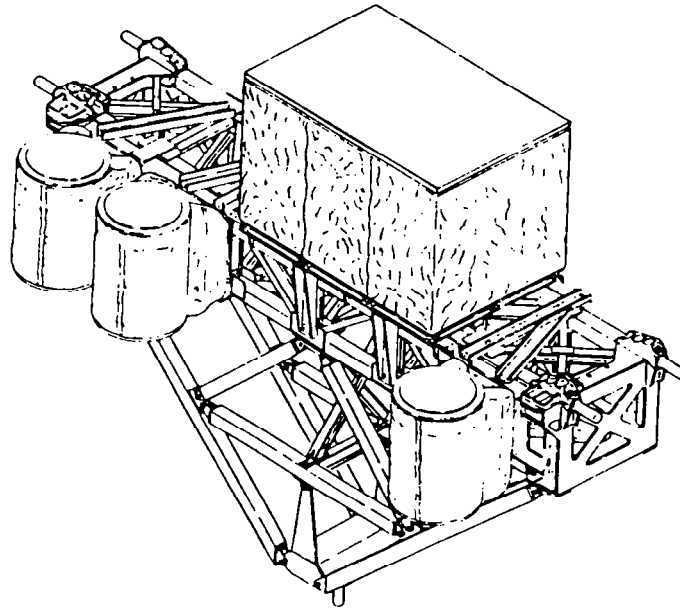
The basic design requirements were as follows:

- Support structure for small number of experiments
- Occupy minimal length of cargo bay

- Standard interface hole pattern
- Provide support at an elevated position
- Employ standard Spacelab pallet trunnion
- Natural frequency between the STS liftoff and landing frequency.

The bridge-like structure is a riveted and bolted truss with machined end fittings which interface with the Spacelab trunnions. The structure is fabricated from aluminum alloy and assembled with stainless steel fasteners.

The first payload to use the support structure was the MSFC managed "OSTA-2" Material Science payload.



Teledyne Brown Engineering's (TBE) dedicated team began their work on the integration of the OSTA-2 (Office of Space and Terrestrial Applications) payload over three years ago, with a basic concept of the written objective, the type of scientific instruments to be flown, and understanding of the Orbiter system and capability.

Sponsored jointly by NASA and the West German Ministry for Research and Technology, OSTA-2 was a payload system carrying two main sets of experiments for the investigation of materials processing in the low gravity environment of space.

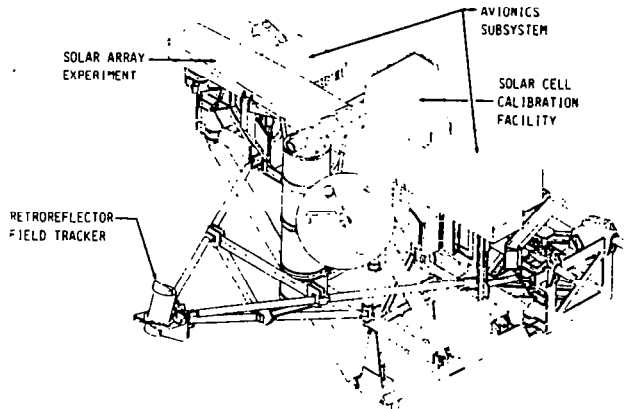
The Materials Experiment Assembly (MEA) experiment, sponsored by NASA, studied new ways of mixing metals in zero-gravity to make advanced alloys and semiconductors not possible on Earth.

The second part of the OSTA-2 was referred to as the MAUS Experiment. MAUS stands for the German Phrase Materialwissenschaftliche Autonome Experimente unter Schwerelosigkeit (Autonomous Material Science Experiments Under Zero Gravity). The MAUS Experiments studied fluid dynamics, the way metals mix and disperse, in zero-gravity environment.

On June 18, 1983, STS-7 was launched, the first Space Shuttle to carry a major payload system (OSTA-2) integrated by PMIC (Payload Mission Integration Contract) of TBE's Space Programs Division.

The next experiment assembly to find the MPRESS compatible to its requirements was the OAST-1 payload. This configuration consists of solar array and solar cell experiments. Unlike OSTA-2, external avionics equipment is required to monitor and control the operation of the experiments.

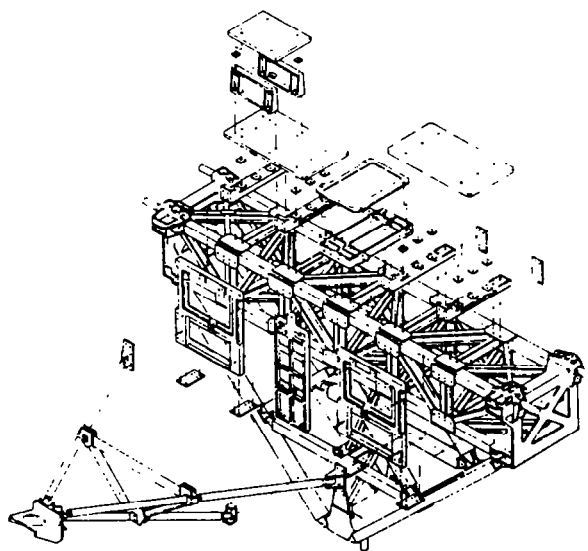
The OAST-1 (Office of Aeronautical and Space Technology) will be carried on the Shuttle in the summer of 1984 and will be the first Shuttle payload dedicated to space technology objectives. It will deploy a large solar array structure (31.5 x 4.0 meters) in space.



A common requirement for many future space projects is the need for large, deployable solar array panels. In order to support such requirements, the OAST-1 payload will demonstrate and obtain dynamics data for such a structure.

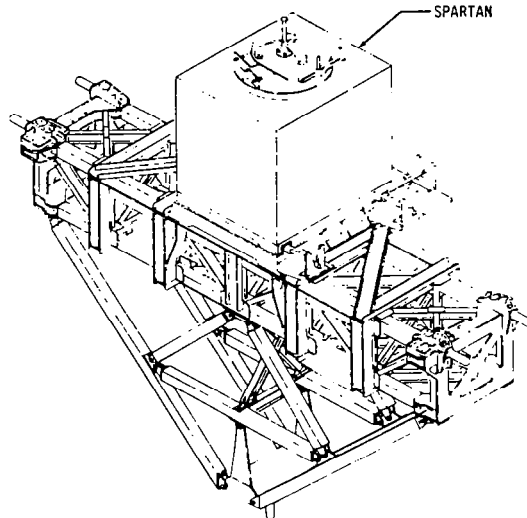
The OAST-1 mission will also carry a solar cell experiment whose objective is to validate calibration techniques used for high altitude balloon flight test for solar cells.

A major aspect of the payload integration task is the design and development of mission peculiar hardware: unique interfacing hardware beyond the basic support structure.

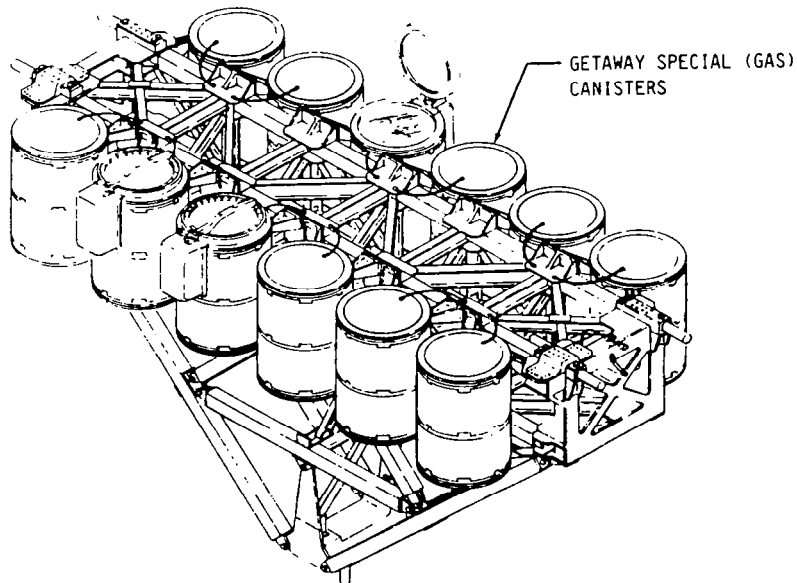


The MPES has recently been adapted for two Goddard Space Flight Center (GSFC) programs – the Spartan and Gas Bridge.

In the Spartan application, the MPES will carry a deployable free-flying satellite. The Spartan flight support structure is an adaptation of the MPES that carries an MSFC release/engage mechanism (REM) with a Spartan carrier attached to the REM. The REM allows the Spartan carrier to be deployed with the RMS.



In the Gas Bridge program up to 12 canisters will be mounted on the sides of the MPES. The Gas Bridge Assembly (GBA) was developed for any combination of 5 to 12 gas canisters, weighing 350 to 400 lbs with varying c.g. envelopes. The GBA design accounts for maximum thermal environments (hot and cold) and it is reusable up to 20 missions with a minimum of recertification and refurbishment. The GBA design is based on the MPES structural concept, which was upgraded to carry 4500 lb for a total payload weight of 6200 lb.

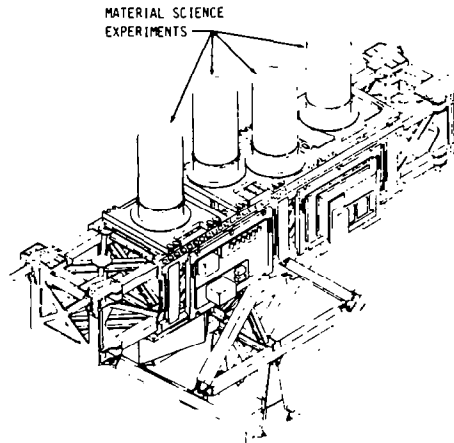




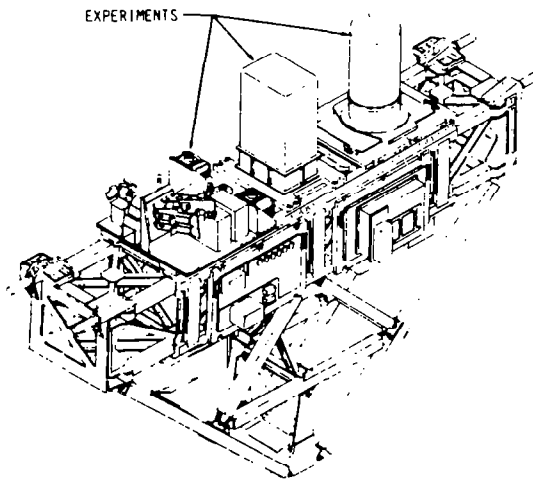
## EVOLUTION TO SMALL PAYLOAD CARRIER SYSTEMS

Design considerations were eventually given to the development of a carrier system which integrated the basic MPRESS with standard subsystem capability: power distribution, command and data, thermal control, etc. This activity resulted in the TBE proposed carrier system named the Small Payload Flight System (SPFS), the Hitchhiker Carrier Design and the new MSFC Materials Science Laboratory (MSL).

Teledyne Brown Engineering is now completing the development of the Material Sciences Laboratory (MSL) for MSFC. The MSL is based on the MPRESS, but will include subsystems for power distribution, command and data handling, high density tape recording of data, environmental control, and low-gravity acceleration measurement. The MSL is scheduled to carry the MSL-2 payload in December 1984.



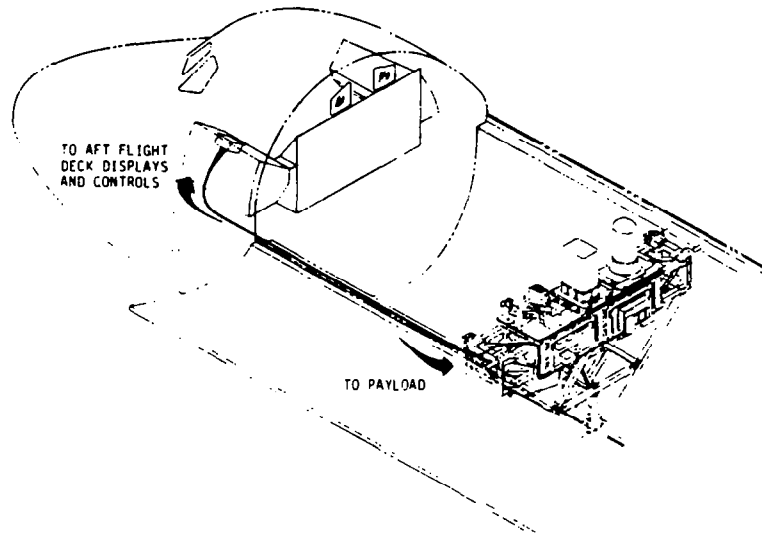
The evolution of the MPRESS-based carrier fleet has led Teledyne Brown Engineering to study the potential need for a commercial carrier system which would be owned and operated by the company and designed to provide low cost, quick turnaround, and frequent flight opportunities to the user. The result of this research is the small payload flight systems (SPFS) representing a step forward in the MPRESS carrier evolution and designed toward the ultimate goal of commercialization in space.



## SPFS SYSTEM DESCRIPTION

SPFS is a carrier system to which experiment equipment can be mounted in the Orbiter cargo bay. It is short in length, can be located in a wide range of stations, and offers the standard one-quarter section allocation of STS resources. In addition, the system is designed to meet launch dates as close as 6 months from manifesting.

Standard experiment-to-carrier interface and a fixed configuration for subsystem equipment are fundamental to the SPFS concept. These features minimize the cost and shorten the schedule for payload integration, and also reduce the time from manifesting to return of experiment data and hardware. The SPFS carrier system with candidate experiment systems mounted and integrated is shown below:



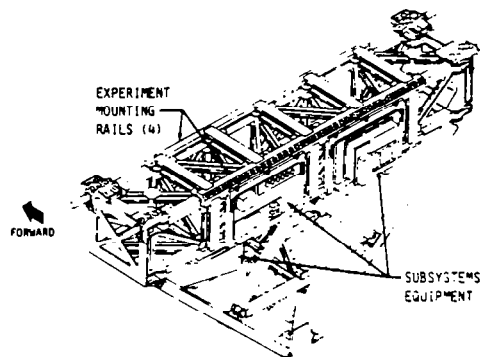
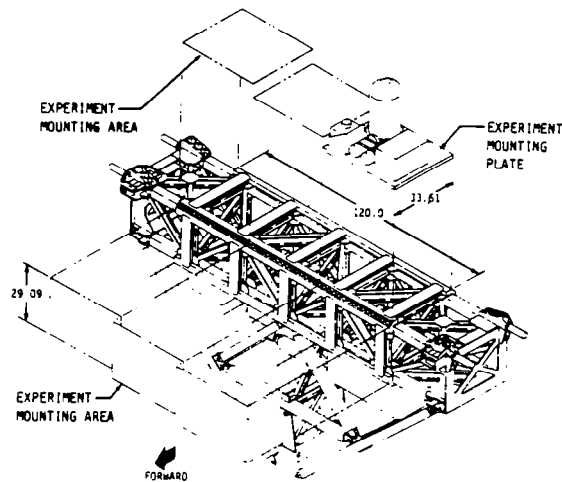
The SPFS with subsystems will support up to three experiments on each mission. Subsystem provisions will include a standard structural mounting system, electrical power switching and distribution, command and data management and environmental control. The subsystem provisions and the nominal envelope of accommodations available to the experiments are as follows:

<u>Subsystem</u>	<u>Total Available</u>
<b>Structural/Mechanical</b>	
Mass capability (lb)	3,000
Mounting area (ft <sup>2</sup> )	58
<b>Electrical Power</b>	
DC power, peak (W)	2,427
DC power, continuous (W)	1,550
Total energy (kWh)	115

Command/Data Management	
Switch/indicator pairs	10
Health data channels	176
Exp. command channels	128
Exp. command channels	16
Timing channels (GMT or MET)	3
ECS	
Coldplates	2
Coldplate heat rejection (kW)	2.1
Cooling internal (kW)	2.1

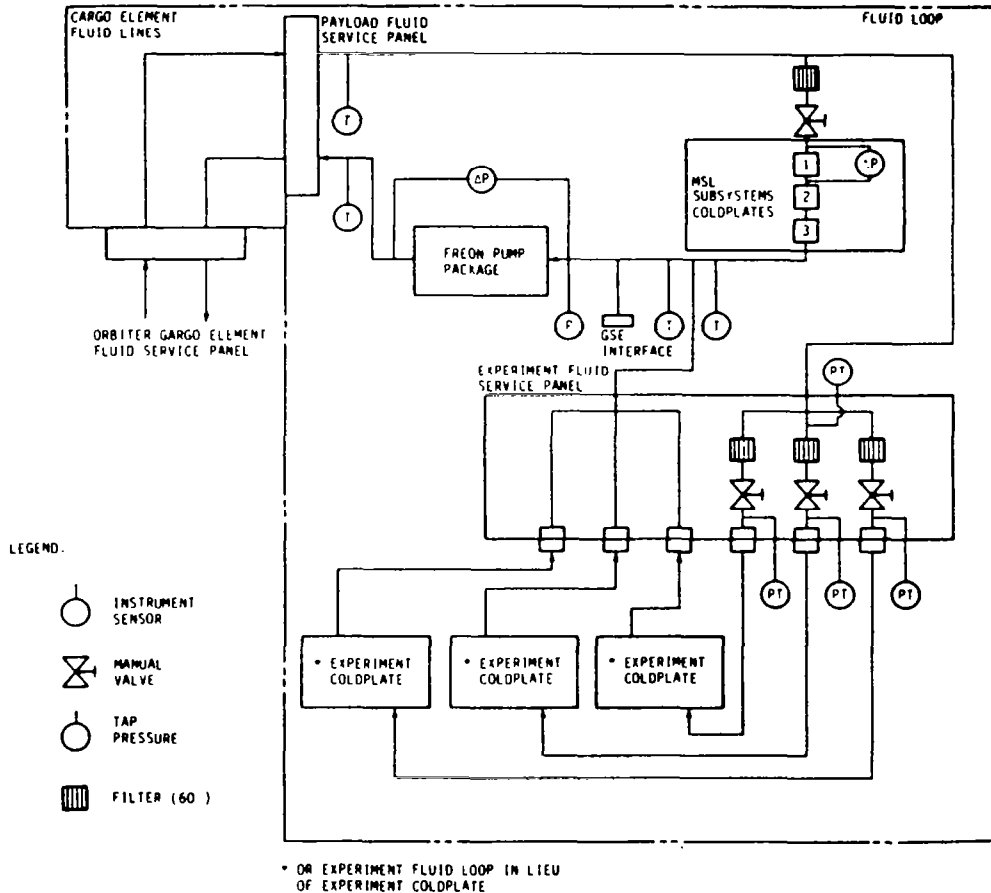
## STRUCTURAL/MECHANICAL SUBSYSTEM

The SPFS carrier provides standard structural mounting for small experiment systems. A structural rail and plate system provides a standardized interface approach which reduces new hardware requirements and recurring analysis for reflight of the carrier.



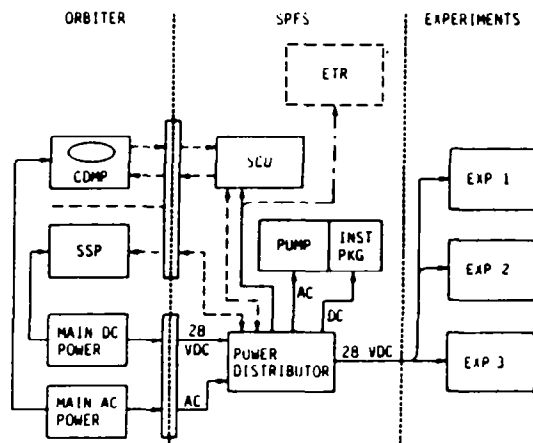
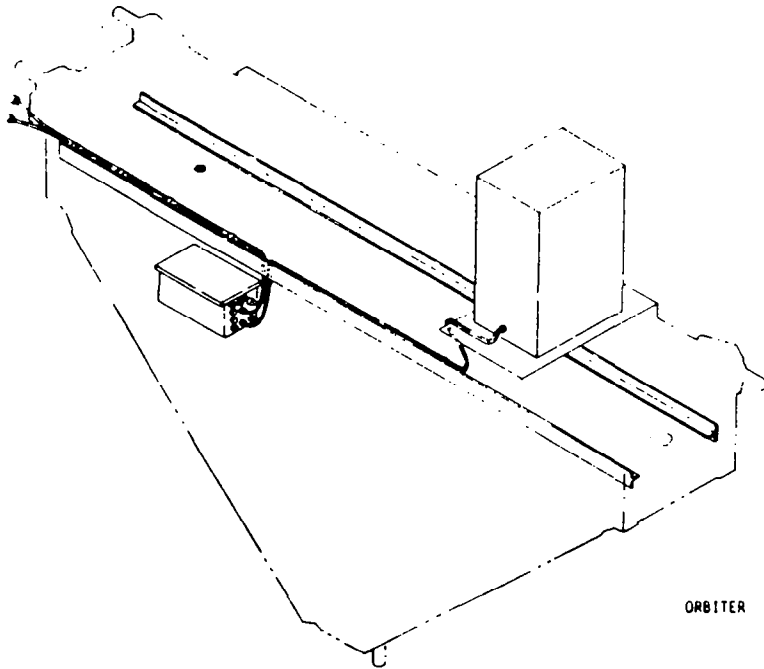
## ENVIRONMENTAL CONTROL SUBSYSTEM

A freon coolant loop system circulates coolant between the SPFS subsystem coldplates, the experiment coldplates, experiment heat exchangers and the Orbiter payload heat exchanger. Freon circulation is provided by the SPFS pump. Multilayer insulation, heater elements, and surface coatings are used, as necessary, for additional thermal control.



## POWER CONTROL SUBSYSTEM

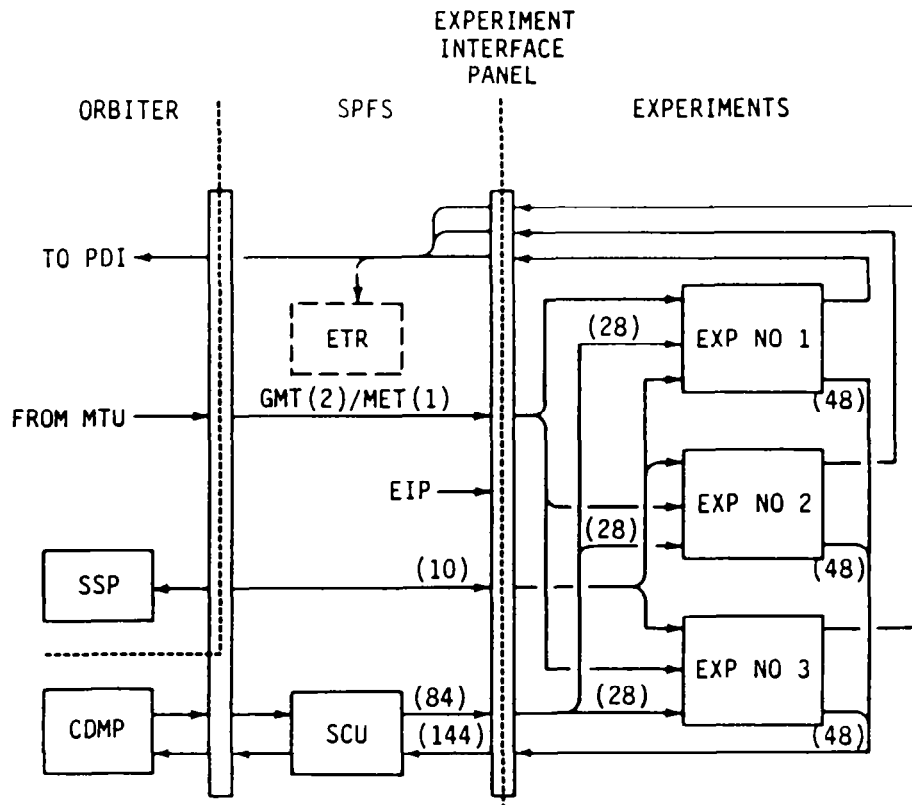
The SPFS concept includes a power distributor to provide 28 Vdc power to the subsystems and experiments. Latching relays in the distributor enable individual circuits to be energized from the AFD by crew commands. A switch on the AFD standard switch panel will activate the power distributor main power, while commands which control power circuits to the experiments are entered at the Command Display Management Panel (CDMP).



## COMMAND AND DATA SYSTEM

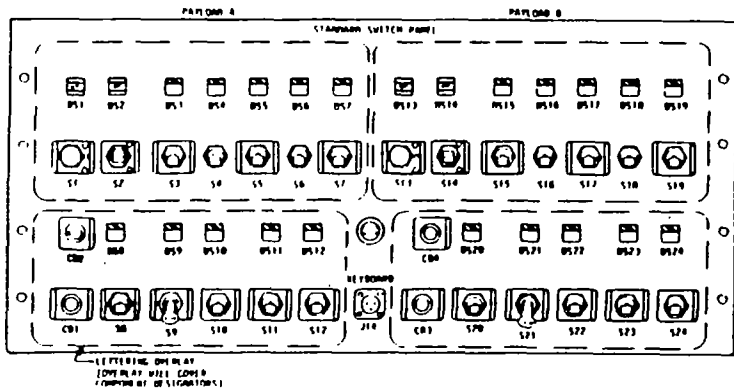
Experiments are expected to range from those that are autonomous to those that will require the full SPFS resources. The following SPFS command and data accommodations are presently planned:

- Aft flight deck standard switch panel operations
- Crew control using the CDMP
  - Crew initiated commands and command sequences
  - Onboard display of health/status data.
- Experiment data downlinking at up to 16 kbps
- Experiment PCM data recording at up to 512 kbps
- Experiment timing accurate to  $\pm 10$  msec
- Preflight interface verification at the user facility
- Crew training.



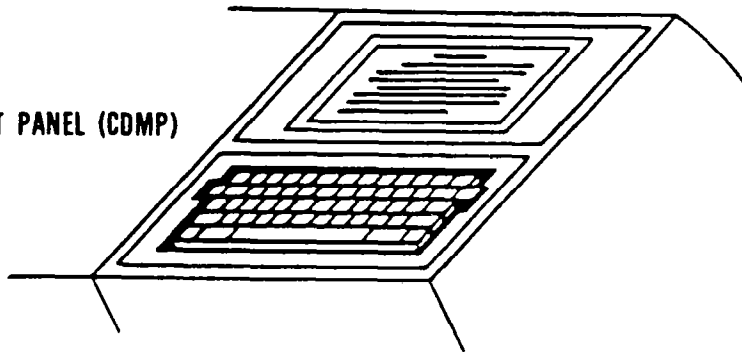
## CREW INTERFACE

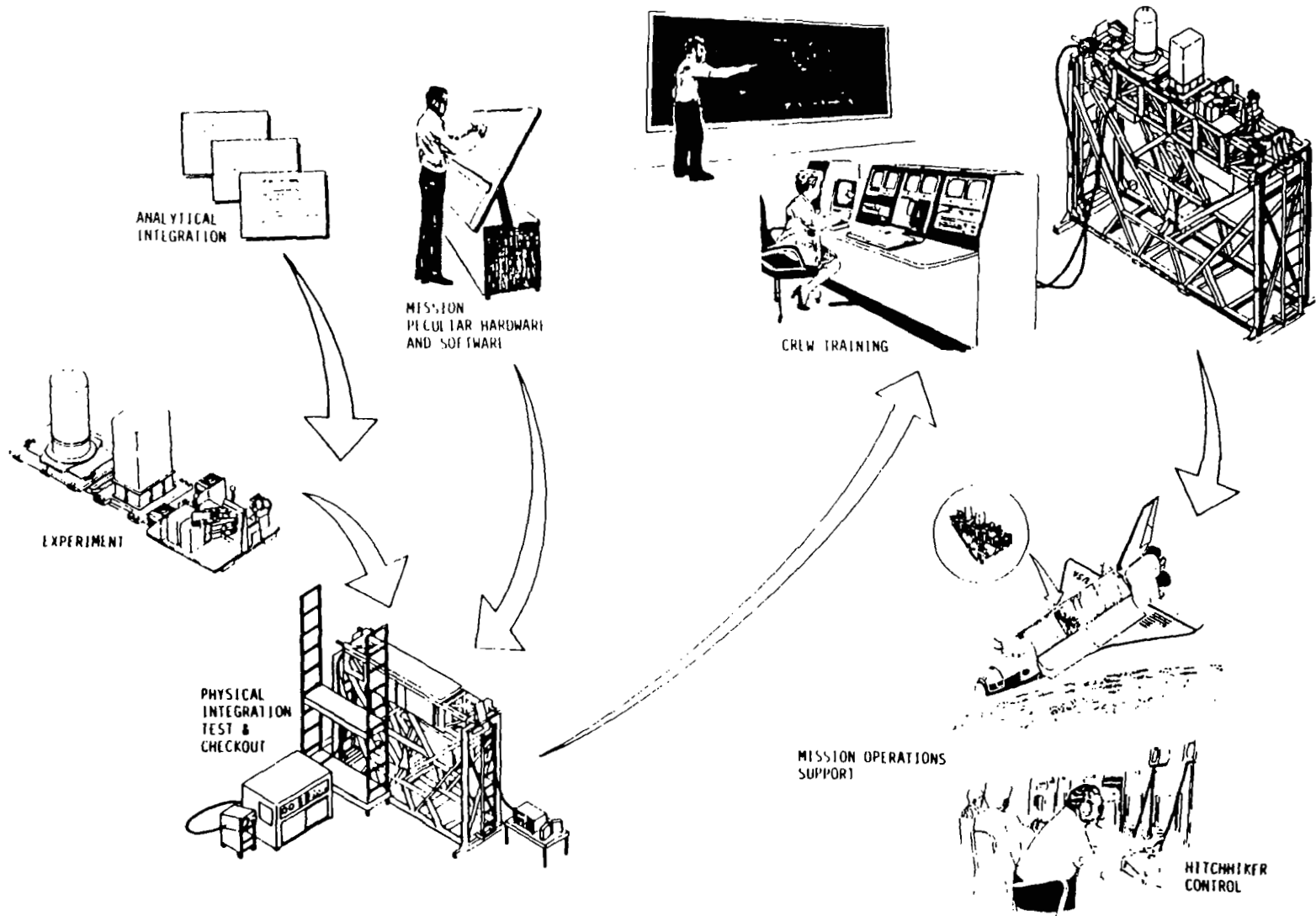
Experiment operation may be autonomous or permit crew interaction from the aft flight deck Standard Switch Panel (SSP) and the SPFS CDMP. Through the CDMP the crew may change the operational mode of the experiment system, initiate a special sequence, change data rate, check critical voltages, etc.



**STANDARD SWITCH PANEL (SSP)**

**COMMAND/DISPLAY MANAGEMENT PANEL (CDMP)**





THE RANGE OF SERVICES WHICH TELEDYNE BROWN ENGINEERING EXPECTS TO PROVIDE TO THE USER.



## COMMERCIAL SPACE SERVICES

by

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### ABSTRACT

This poster paper provides an overview of space service opportunities as identified by a Wyle Laboratories' research team. This effort is funded by the NASA Commercial Task Force to support policy and planning efforts of the government and to accelerate transition of space operations to the private sector. A better understanding of potential commercial opportunities for space services is needed to aid in the promotion and implementation of new private enterprises as encouraged by current administration policy.

Through the use of a baseline space scenario, a variety of space hardware, services, and commercial activities are identified and related on a time-phased basis. A model is presented to relate the potential functions of government and the private sector in a commercialized space environment during the period 1984 to 2004. Barriers, incentives and key issues are likewise identified and addressed to aid in the implementation of private sector activities for space-related programs. Broader awareness, legislative actions, incentive development and benefit analyses are considered in the presentation. The time-phased plan developed as the final product of the study contract provides a useful planning and management tool, allows broader communication, and supports overall space commercialization program assessment.

### DISCUSSION

Wyle was recently awarded a new contract by NASA Headquarters to support the NASA Commercialization Task Force. The Wyle team, consisting of personnel from Huntsville, Hampton, and El Segundo has supported the development of the new policy and position papers needed to stimulate expanded commercial activities in space programs.

Commercial opportunities in space encompass involvement of the private sector for products and services derived in the space environment and for support services to space endeavors. Potentially profitable enterprises related to:

- Earth and ocean observations
- Communications
- Materials processing
- Industrial and special commercial services.

To achieve private sector investment in, ownership of, and operation of various activities as a profit-making venture, certain NASA initiatives must be undertaken to stimulate and support private sector involvement. Wyle is helping NASA to identify and implement those new initiatives and communication methods.

The long-term development and use of space will require the continuing application of a large array of equipment, facilities, and operational processes. Not only will new opportunities arise for the development and commercialization of new products as a result of the special environment afforded by space, but likewise, many new service-related opportunities can now be anticipated. The Wyle team is supporting NASA by identifying potential space services required to support a broad variety of public, private and military space endeavors now in planning and development.

Commercial space services in support of space applications, technology development, military and industrial activities are anticipated for a broad range of activities, both ground and in-space related. Wyle has identified numerous service functions. In addition, related services and desirable government incentives, and actions needed to accelerate the commercialization process have been identified and addressed in the Wyle study program.

To aid in the study, a model was developed by Wyle which helps to relate the potential functions of government and the private sector in a commercialized space environment. The time-phased listing of potential involvement of the private sector, developed as the final product of the study, should provide a useful planning and management tool, allowing broader communication, and enhancing the overall assessment of the space commercialization program.

A Fee-For-Service Laboratory attached as a module to the planned orbiting Space Station is envisioned to be one area where the private sector can contribute both technically and materially to NASA space commercialization efforts in general, and to private sector involvement in the Space Station mission in particular. This laboratory, as an example of a typical commercial space service activity, can provide an important and necessary vehicle to meet private-sector needs in the commercialization of emerging technologies such as materials processing in zero gravity. Technical and economic assessment of a Fee-For-Service Laboratory is being proposed by Wyle Laboratories. This Lab will have many positive advantages for both the government and industry factions which it will serve.

The architecture of the Fee-For-Service Laboratory will evolve through detailed analysis of user requirements and associated equipment operation. Surveys which are now in progress and those completed in the past have revealed that industry has both needs and interests in space-based R&D; however, there is a strong reluctance on their part to pursue the independent development of supporting facilities and equipment. The Wyle Fee-For-Service Laboratory could provide both the needed space-based facilities/equipment as well as trained personnel to perform tests and/or to generate samples in accordance with user specifications. Consideration of industry needs, individually and collectively, would ensure the development of a general purpose laboratory of sufficiently broad capability, to meet industry needs in an orderly rather than in a piece-meal fashion.

In addition Wyle is investigating other space concepts and ventures to support development and testing of large space structures, energy conversion and storage devices, and advanced materials needed to advance our technological base and broaden commercial operations.

In the longer term, and projecting into the next century, the expected exploration and exploitation of outer space could lead to public and private enterprises of considerable scope and benefit to the human race. A selection of the types of long term space endeavors now being identified and assessed for commercial potential include the following:

- Hazardous Waste Disposal in Space
- Global Environmental Assessments (CO<sup>2</sup>, Freon, Acid Rain, Etc.)
- In-Space Agriculture
- Tethers For Mass/Momentum Transfer
- Large Space-Based Power Systems
- Space Industrial Parks
- Space Hotels and Recreational Facilities
- Lunar Base Construction and Operation
- Extra Terrestrial Mining and Mineral Processing

# DIRECTIONAL SOLIDIFICATION OF FLAKE AND NODULAR CAST IRON DURING KC-135 LOW-G MANEUVERS

by

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and

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## ABSTRACT

Alloys solidified in a low-gravity environment can, due to the elimination of sedimentation and convection, form unique and often desirable microstructures. One method of studying the effects of low-gravity (low-g) on alloy solidification has been the use of the NASA KC-135 aircraft flying repetitive low-g maneuvers. Each maneuver gives from 20 to 30 seconds of low-g which is between about 0.1 and 0.001 gravity.

A directional solidification furnace was used to study the behavior of off eutectic composition cast irons in a low-g environment. The solidification interface of hypereutectic flake and spheroidal graphite cast irons has been slowly advanced through a rod sample, 5 mm in diameter. Controlled solidification has been continued through a number of aircraft parabolas. The known solidification rate of the sample was then correlated with accelerometer data to determine the gravity level during solidification for any location of the sample. The thermal gradient and solidification rate were controlled independently. Three types of samples were run: hypereutectic flake graphite cast iron with low and high ( $\approx 0.2\%$ ) phosphorous content and hypereutectic spheroidal graphite cast irons obtained through treatment with metallic cerium. Samples run on the KC-135 aircraft exhibited bands of coarser graphite or of larger nodules usually corresponding to the regions solidified under low-g. Samples containing high P (used in order to determine the eutectic cell) exhibited larger eutectic cells in the low-g zone, followed by a band of coarse graphite.

## INTRODUCTION

It has been postulated [1] that gravity levels during solidification could have a significant effect on growth, macrostructural heterogeneity, and the size and distribution of macrophases in cast iron. During the solidification of hypereutectic irons, density differentials between light graphite material floating in heavier liquid could be expected to cause gravity-driven segregation. Other density differentials in the melt could be caused by the segregation of lighter alloying components such as sulfur or of heavier alloying components such as rare-Earth elements.

Thus, although cast iron is one of the most complex alloys used by modern industry, low-g experiments with cast iron could offer an excellent opportunity to study the effects of convection and sedimentation on alloy solidification. The complexity of the alloy combined with the demand for its usage (cast iron foundries produced 3.1 million tons of casting monthly worldwide in 1982, and over 600,000 tons in the United States [2]) make advances in cast iron casting technology of great interest to industry.

In June 1981, NASA began a Technical Exchange Agreement (TEA) with John Deere Company [3] to collaborate in a series of low-g solidification experiments of commercial cast iron utilizing NASA's low-g aircraft [4,5]. Of particular interest during this study was finding the effects of low-g on graphite nucleation and growth. The first series of experiments involved gas quenching of cast iron melts during the 20-40 sec, low-g time afforded by a KC-135 or F-104 low-g parabola. These experiments were partially successful [6,7]; however, many were inconclusive because complete solidification of the iron sample in the 20-40 sec low-g period could not be attained without producing predominantly white iron [8]. This paper describes the result of a parallel study undertaken, partially in support of the Deere/NASA TEA, in which directional solidification was employed. Directional solidification has many advantages over the quenched ingot methods for alloy solidification experiments, especially for low-g solidification experiments in the KC-135. In directional solidification, the solidification interface can be slowly advanced through a rod of the sample. Controlled solidification can continue through a number of aircraft parabolas. The known solidification rate (R) of the sample can then be correlated with accelerometer data to determine the gravity level during solidification for any location on the sample. The thermal gradient (G) and solidification rate can be controlled independently; whereas, for the quench ingot method the complexity of the three dimensional cooling problem makes their control very difficult. Knowledge of G and R allows quantitative expression of the influence of foundry variables on casting microstructures. The effect of the G/R ratio is summarized in Figure 1. It can be seen that as the G/R ratio is lowered or as the undercooling is increased the solidification interface changes from planar to cellular and then to dendritic. Eventually, heterogeneous nucleation will occur ahead of the solid-liquid interface (independent nucleation or endogeneous solidification) resulting in irregular interface due to grain nucleation and growth in microvolumes away from the interface. This last type of solidification is characteristic for cast iron solidifying with austenite-graphite eutectic. The thermal conditions associated with the solidification sequence described in Figure 1 are given in Figure 2.

## PROCEDURE

The basic experimental unit used in this research was a G.E. prototype ADSS furnace [9], which was modified for use in the NASA KC-135 low-g aircraft (Figure 3) primarily by adding a portable quench block water circulation system [10]. A thermal profile of an empty crucible measured with the maximum furnace temperature of approximately 1500°C is given in Figure 4 [10].

Different thermal gradients can be obtained by varying the maximum temperature in the furnace cavity, and the correlation between the thermal gradient in an empty crucible and the maximum furnace temperature is shown in Figure 5 [10]. Samples were directionally solidified during a series of up to 10 KC-135 low-g maneuvers. Figure 6 shows the KC-135 executing a maneuver, and Figure 7 illustrates schematically the gravity level variation during the maneuvers.

The flight experiments were run at constant R, with the furnace being translated vertically upwards while the KC-135 aircraft was flown through low-g parabolas.

## RESULTS AND DISCUSSION

A detailed discussion of the result of this study will be presented elsewhere [11]; in this paper it is intended only to highlight the findings relating to the effects of gravity on cast iron microstructure. The irons investigated [11] were commercial composition, hypereutectic, and fell within one of the following three categories: cerium containing cast irons, low phosphorus flake graphite (FG) irons, and high phosphorus flake graphite irons.

### Low Phosphorus Flake Graphite Irons

The low magnification metallographic structures of two hypereutectic iron samples from the same heat, directionally solidified during KC-135 low-g maneuvers, are given in Figure 8.

The gradient in the furnace was  $G = 327^{\circ}\text{C}/\text{cm}$ , and the growth rates were 5.5 and 1.1 mm/min respectively. The gravity environment for each region of the two samples can be read on the scales under the microstructures.

For the first sample, solidified at a rate of 5.5 mm/min, it can be seen that a very distinctive coarse graphite zone can be associated with the first low-g zone. Immediately, after the low-g zone, there is a zone of fine graphite before the graphite coarsening that characteristically occurs at the end of the sample.

A coarse graphite zone was also associated with the fourth low-g zone on the second sample, solidified at a rate of 1.1 mm/min. Then again, a lot of coarse graphite forms toward the end of the sample.

Since, in hypereutectic cast irons the partition coefficient of carbon between the solid and the liquid phases is higher than 1.0 and since coarsening due to sulphur segregation would not be expected to be as marked as that in Figure 8, the only viable explanation for the graphite coarsening seems to be the occurrence of flotation.

Coarsening of the graphite in some of the low-g zones could be explained by the following two hypotheses.

The first hypothesis is based on the lack of flotation in the low-g zone. This may allow primary graphite to be incorporated in the solidification front.

A second hypothesis is similar in nature with the one used to explain dendrite coarsening as a result of convective flow in a high-g environment. Since graphite is the leading phase in the solidification process of the austenite-graphite eutectic, in a high-g field, convection may break up the tips of the leading graphite and move them farther away in the liquid, where they can serve as nuclei for primary graphite and/or eutectic grains. In either case, the net result will be larger graphite flakes.

## Cerium Containing Spheroidal Graphite Irons

A composite microstructure of spheroidal graphite iron directionally solidified during KC-135 maneuvers is given in Figure 9. The furnace temperature for this sample was 1350° resulting in a gradient of 232°C/cm. The solidification rate between the melt interface and the first low-g zone was 6.33 cm/min (run up part), and 0.194 cm/min for the rest of the sample. It is obvious from Figure 9 that a high concentration of rather large nodules occurs in the region corresponding to the second low-g parabola, just before the third and fourth low-g parabolas, and at the fifth low-g parabola. A clearly defined flotation zone is obvious at the end of the sample, before the shut down of the furnace.

Also, a ground base experiment was run on a sample from the same heat under the same experimental conditions, except variable gravity. The structure along the sample was very similar to the one which can be seen on the run up part of the sample on Figure 9, with a rather uniform distribution of larger nodules between the small nodules.

The best explanation for the banding in the flight sample in Figure 9 seems to be flotation. The solidification process along the flight sample in Figure 9 was modeled using Stokes' law using the values given in Table I. It was found that the nodule size of the graphite bands was such that their flotation speed was slightly greater than the solidification interface speed in high-g but negligible compared to it in low-g. Thus, flotation and low-g zones can explain the occurrence of bands with big graphite nodules (flotation zone), both in the low-g zones and out of the low-g zones. It then seems reasonable to conclude from these results that graphite flotation in SG irons of high carbon equivalent composition can be prevented by solidifying the iron in a low-g environment.

## High Phosphorus Flake Graphite Cast Iron

High phosphorus iron was studied in order to study the influence of gravity on the grain size of cast irons. It is well known that irons containing high P contents will tend to solidify with rather high amounts of phosphide eutectic (steadite). Steadite tends to solidify at the grain boundaries and a special etching method allows for determining the eutectic grain size and shape. Low magnification composite micrographs of three high phosphorus samples from the same heat are given in Figure 10. The top and middle samples were solidified on the KC-135, the bottom was run as a one-g control.

The furnace temperature for all samples was 1500° resulting in a gradient of 284°C/cm. The solidification rate for all three samples (after a run up at 14.2 mm/min for the top sample) was 4.9 mm/min. For the control sample after the primary melt interface the structure changed gradually from type A graphite, no cells, to type D graphite, cells, and then remained unchanged for most of the sample, until the sample was pulled out of the furnace, resulting in a carbidic structure due to the high cooling rate.

In the second flight sample (middle Figure 10) the structure changed suddenly from type A graphite, no cells, to type D graphite, cells, at the first transition from the high-g to the low-g zone. Then, as the g environment was changed again the structure exhibited again type A graphite corresponding to the beginning of the high-g zone. A similar transition can be observed on first flight sample (top, Figure 10) in the middle of the first high-g zone after a low-g zone. Also, it is obvious that the cells are considerably larger in the first low-g zone than in the other regions of the sample.

A detailed evaluation on the eutectic cell count on the flight samples showed that despite a large scatter in the data the pattern for the variation of the eutectic cell count given in Figure 11 for the low-g and high-g zone seems to be implied. Thus, the data indicates that gravity enhances cell multiplication, and that the lack of convection in a low-g environment results in a lower number of eutectic cells during solidification.

This phenomena can be explained by a higher undercooling before solidification in the low-g zone. The experimental evidence for this is the abrupt transition from type A to type D graphite observed on both flight samples at the transition from some high-g zones to low-g zones (see Figures 10 top and middle, and Figure 12). Actually the transition is really from a planar solidification (no grain boundaries were revealed by deep etching) to an irregular solidification (Figures 1 and 2).

## CONCLUSIONS

In low-g environment, no flotation occurs even in SG irons with carbon equivalent as high as 5%. This opens the way for production of iron-carbon alloys with high carbon content (e.g. 10%), actually of iron-carbon composite materials in low-g environment. These materials could have a highly oriented structure as a result of directional solidification if flake graphite structures are solidified. Such a material will have a high thermal conductivity and strength in the direction of the heat flow, and low values for the above properties in a direction perpendicular to the heat flow. Also, composite Fe-C materials with uniformly dispersed spheroidal carbon particles could be produced by the same technique. By increasing the phosphorus content in hypereutectic FG irons, it was possible to document the influence of the low-g environment on the eutectic cells. It was observed that the eutectic cell count tends to decrease in a low-g zone, which means that convection currents existing in a high-g environment will produce cell multiplication by a mechanism not yet fully explained.



## REFERENCES

1. Frankhouser, W. L.: Materials Processing Threshold Report, II. Use of Low Gravity for Cast Iron Process Development. Final Report, Contract NAS8-33518, February 1980.
2. "17th Census of World Casting Production – 1982", Modern Casting, Vol. 73, No. 12 (December 1983), pp. 22-23.
3. Technical Exchange Agreement between National Aeronautics and Space Administration and Deere and Company in the area of Materials Processing in Low-Gravity, signed June 29, 1981.
4. Neu, L. R. J.: JSC Reduced Gravity Aircraft User's Guide. JSC-17385, May 1981.
5. Poorman, R. M.: F-104 Low-Gravity Calibration Test for Materials Processing in Space Precursory Experiments. NASA TM-78278, March 1980.
6. Stefanescu, D. M. and J. C. Hendrix: Report on KC-135 Cast Iron Samples No. Thur. No. 1 Through Fri. No. 5, Contract NAS8-34724, May 1982.
7. Fosbinder, L. L. and Klann, R. W.: NASA Solidification of Cast Iron in Zero Gravity. Deere and Co. Technical Report No. 173, August 1982.
8. P. A. Curreri, G. A. Smith, and G. Workman, "The Feasibility of Low-G Grey Solidification of Nodular Iron in the F-104 Experimental Furnace Package," NASA TM-82527, April 1983.
9. General Electric, Space Science Laboratory, Philadelphia, PA., NASA Contract Number NAS8-31536, (November, 1975).
10. P. A. Curreri, D. M. Stefanescu, and J. C. Hendrix, "Preliminary Science Report on the Directional Solidification of Hypereutectic Cast Iron During KC-135 Low-G Maneuvers, NASA TM-82528 (April, 1983).
11. Hendrix, J. C., P. A. Curreri, and D. M. Stefanescu, "Directional Solidification of Flake and Spheroidal Graphite Cast Iron in Low and Normal Gravity Environment," paper 84-99, 88th AFS Casting Congress, St. Louis, MO, May, 1984.

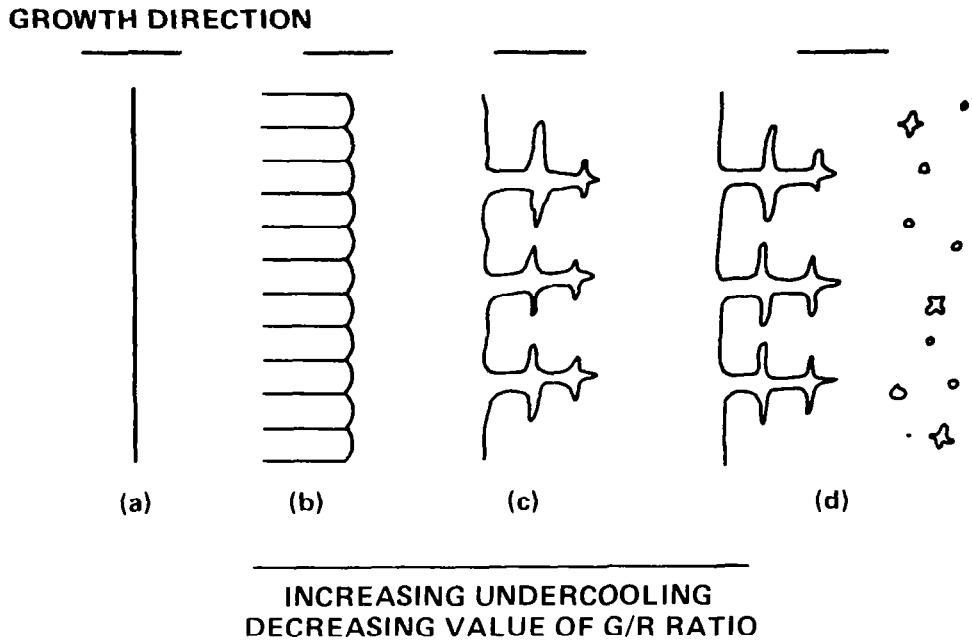


Figure 1. Influence of G/R ratio on interface morphology: (a) planar interface; (b) cellular interface; (c) dendritic interface; (d) irregular interface.

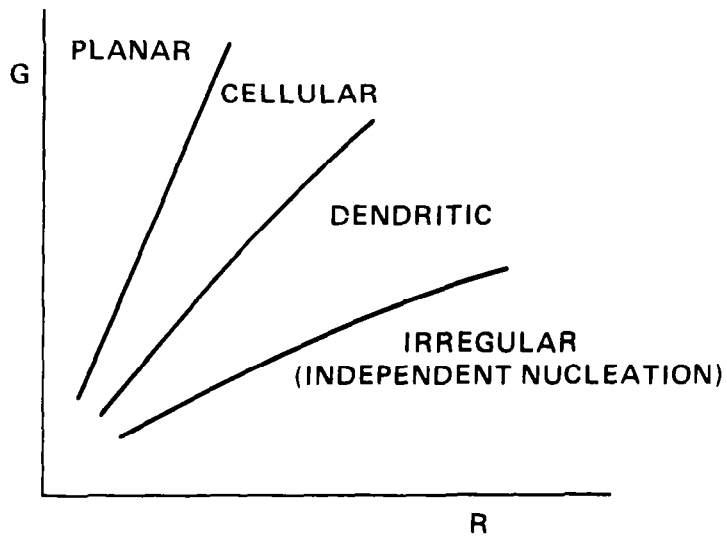


Figure 2. Influence of temperature gradient, G, and growth rate, R, on the interface morphology of a given alloy.

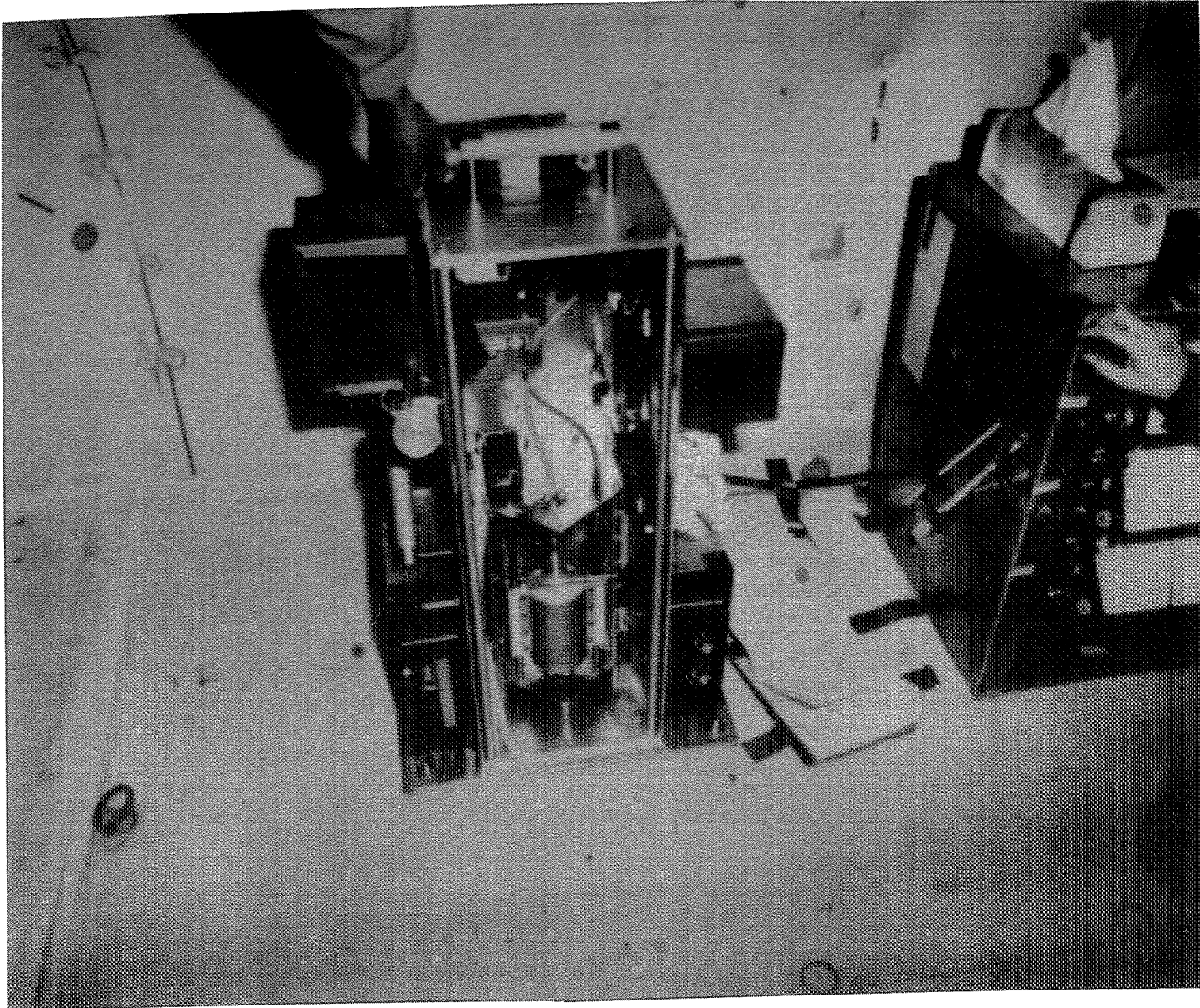


Figure 3. ADSS-P furnace installed in the KC-135 aircraft.

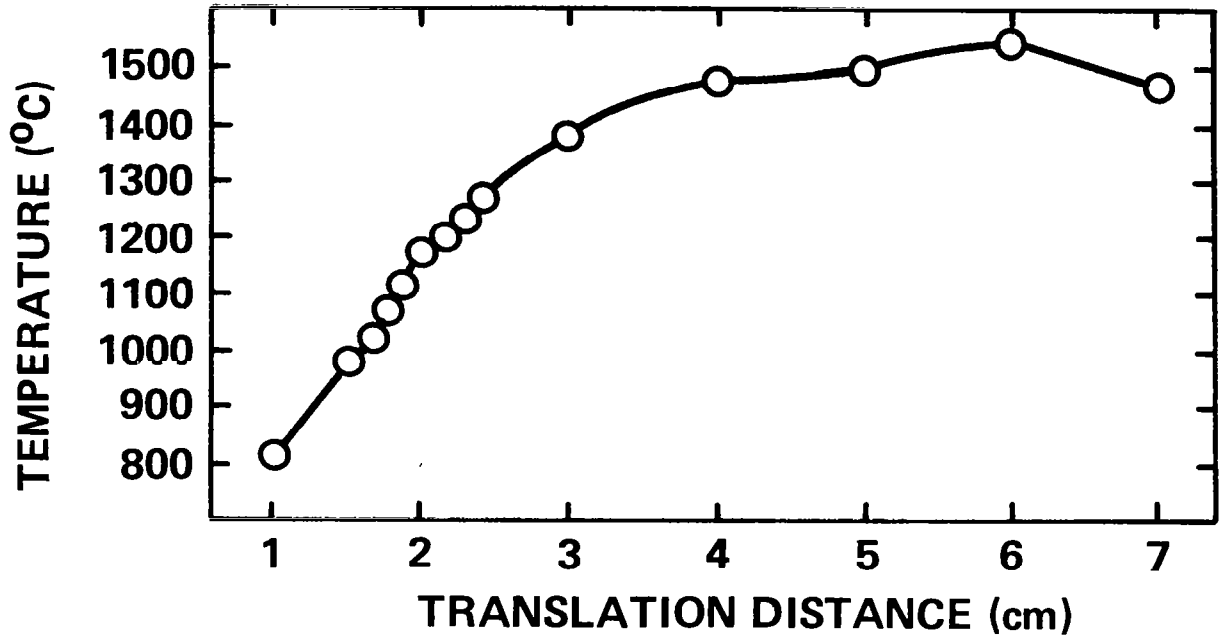


Figure 4. The thermal profile of an empty crucible for a furnace temperature of 1500°C.

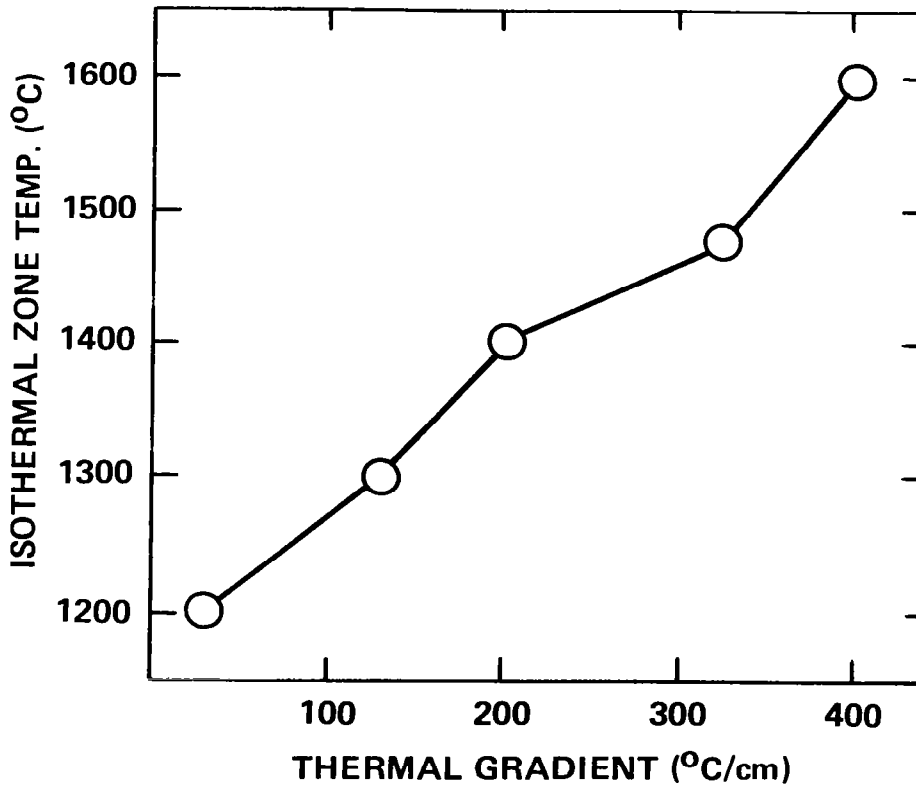


Figure 5. Thermal gradient (in an empty crucible) versus furnace temperature.

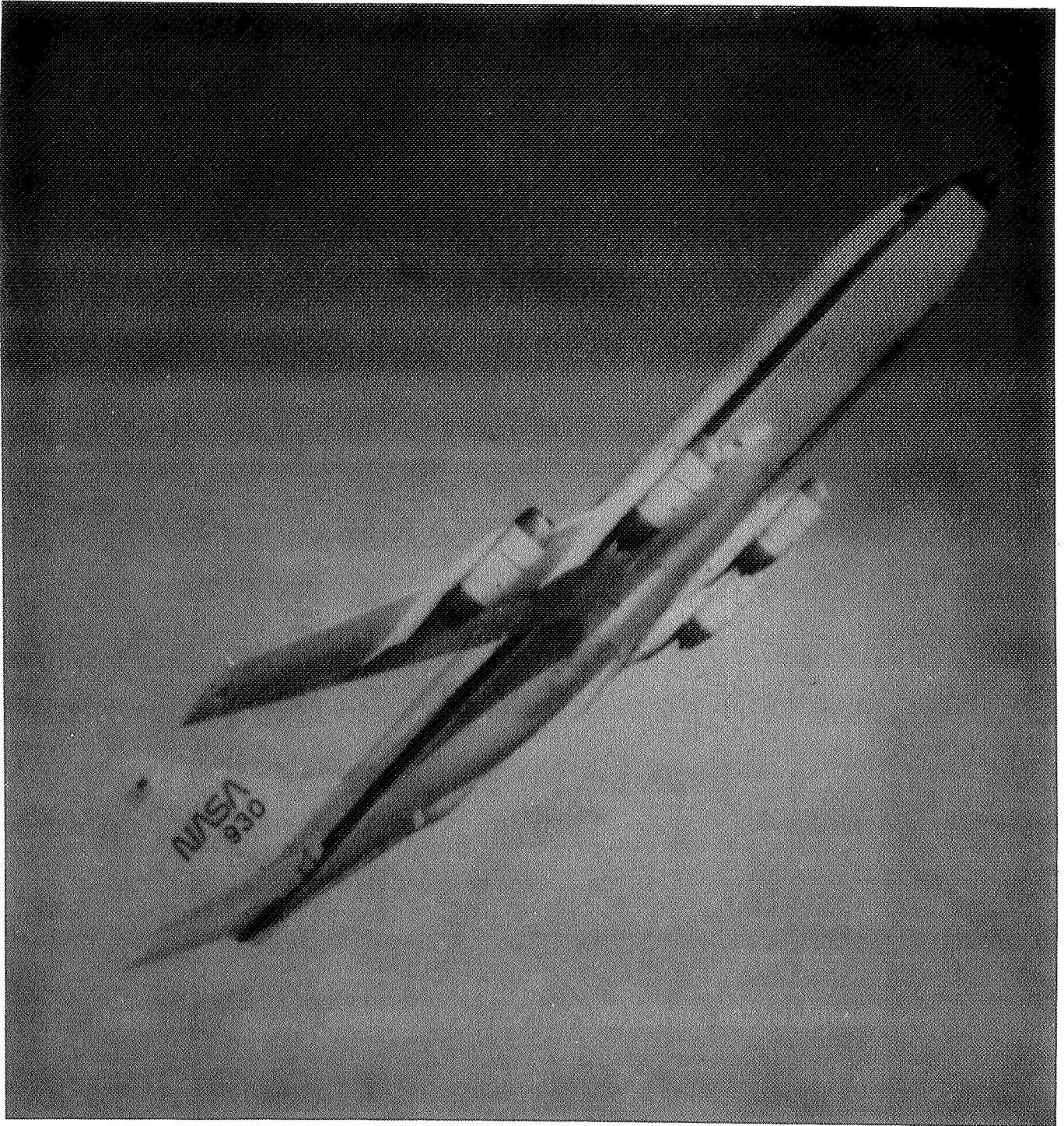


Figure 6. KC-135 aircraft during a low-g maneuver.

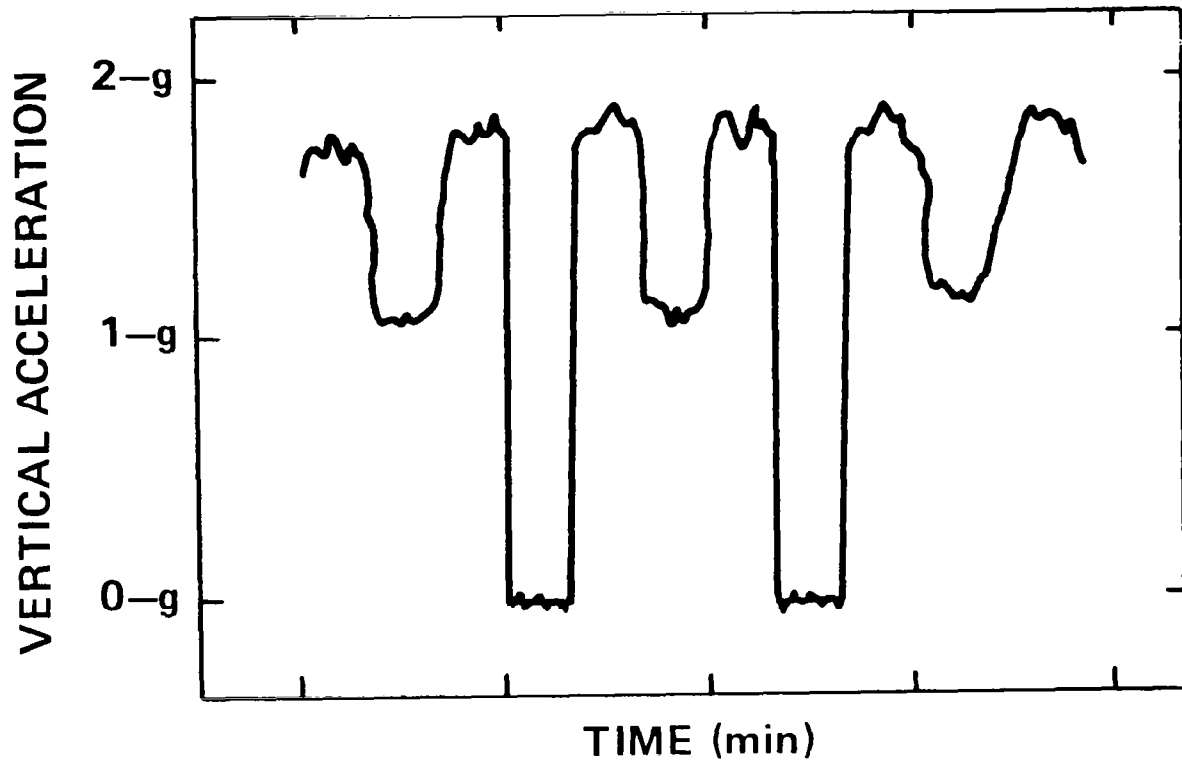
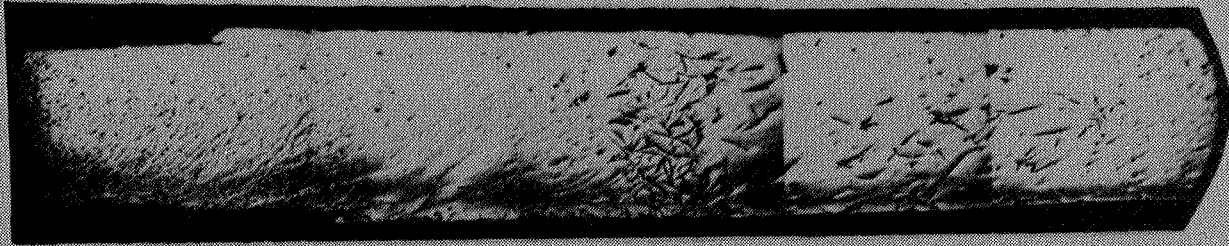


Figure 7. Schematic showing gravity level fluctuations during KC-135 multiple low-g maneuvers.

HYPEREUTECTIC CAST IRON  
SOLIDIFIED DURING KC-135 LOW-G MANEUVERS

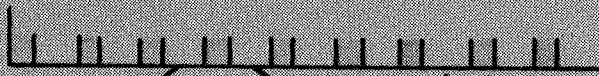
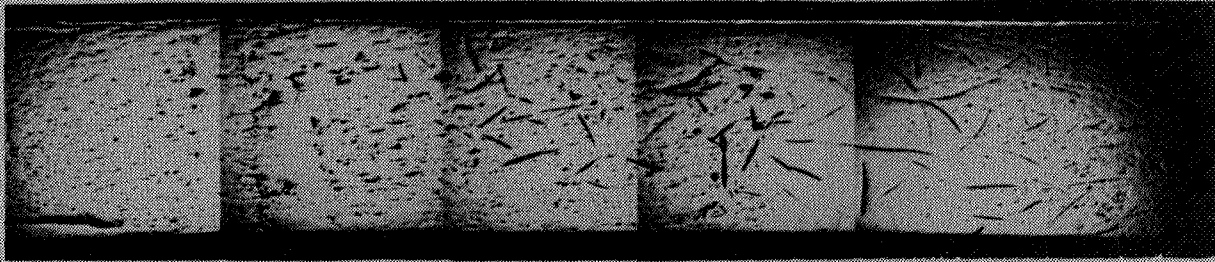
TRANSLATION RATE = 5.5 MM/MIN



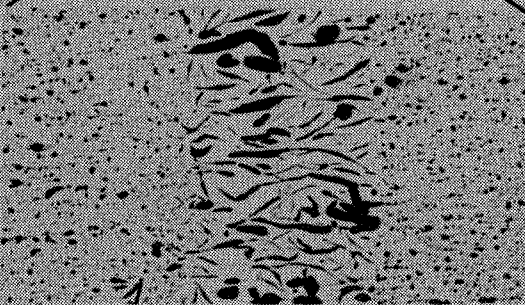
1 MM

LOW-G HIGH-G

TRANSLATION RATE = 1.1 MM/MIN



LOW-G  
HIGH-G



← INCREASED MAGNIFICATION  
5.5 x

Figure 8. Low magnification composite micrograph of the KC-135 directionally solidified hypereutectic iron flight samples.

**SOLIDIFIED DURING KC-135 LOW-G MANEUVERS**

**0.17% Ce Cast Iron**

**Translation Rate - 2.0 mm/min**

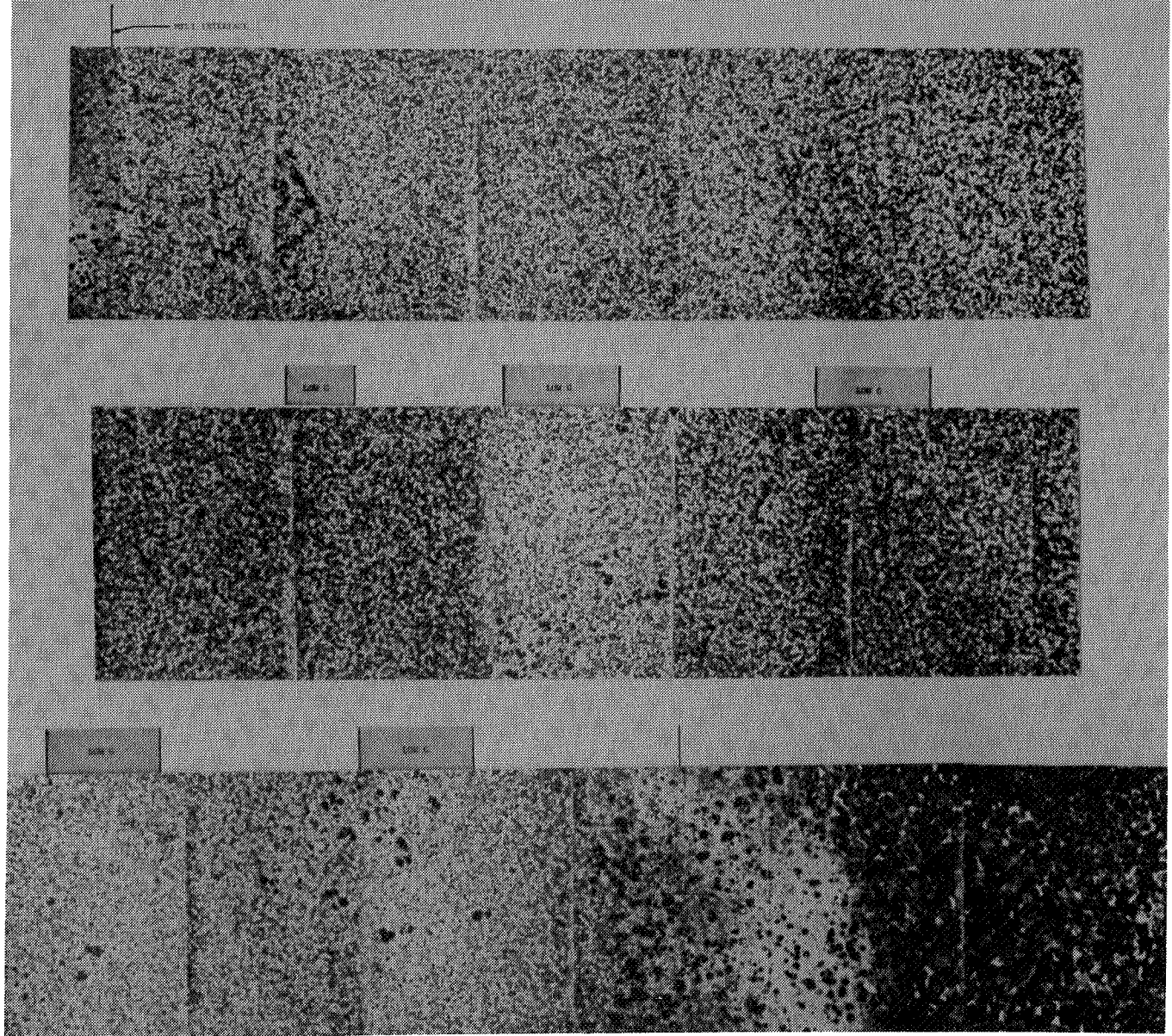


Figure 9. Low magnification composite micrograph of a KC-135 directionally solidified SG iron sample.



**SOLIDIFIED DURING KC-135 LOW-G MANEUVERS**

**0.21% P Cast Iron**

**Translation Rate : 4.9 mm/min**



Figure 10. Low magnification (originally x 12) composite micrographs of high phosphorus hypereutectic flake graphite iron samples: bottom – ground-based sample; middle – flight sample; top – flight sample.

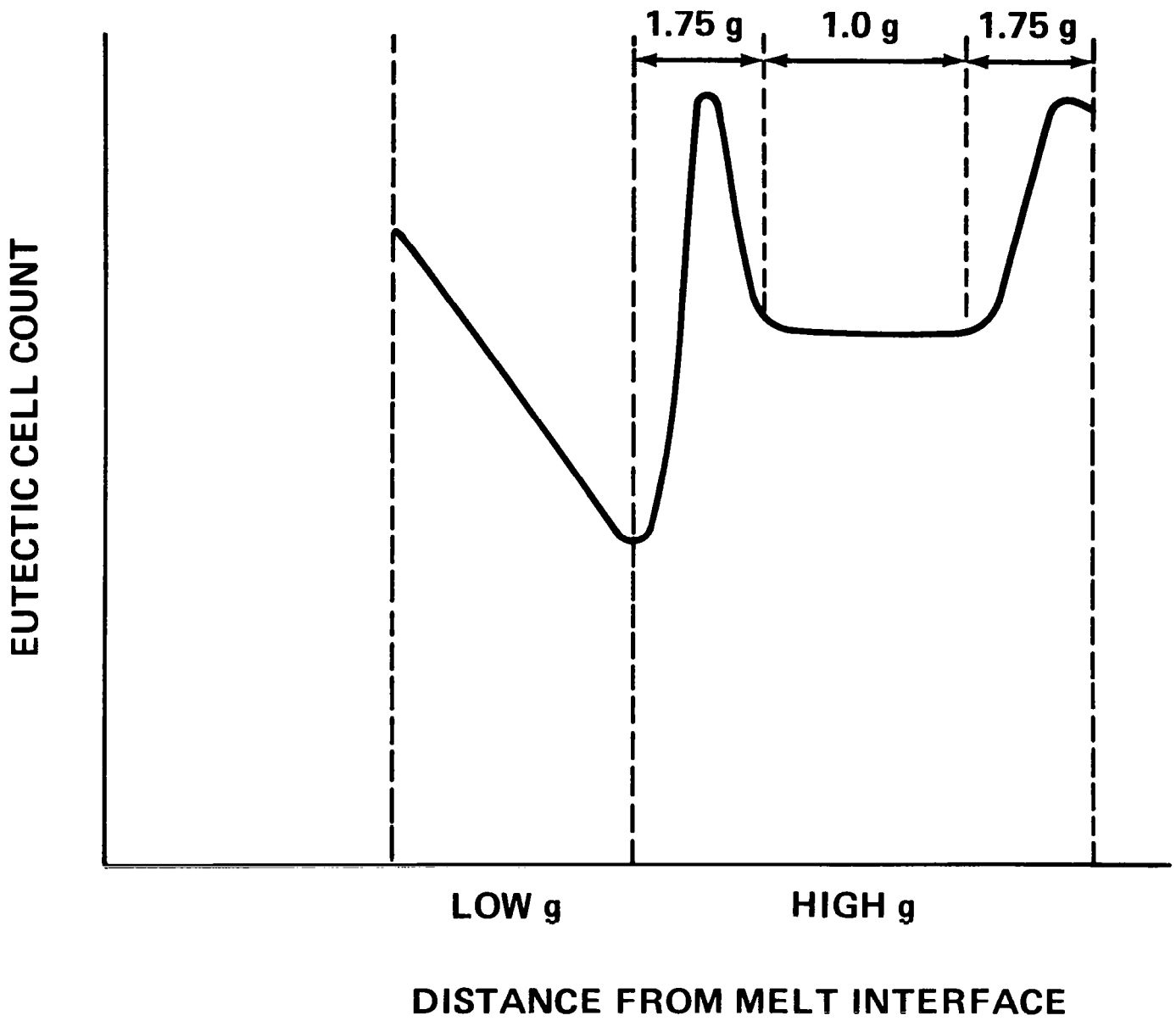


Figure 11. Schematic showing the influence of the gravity level on the eutectic cell count in high phosphorus flake graphite cast irons.

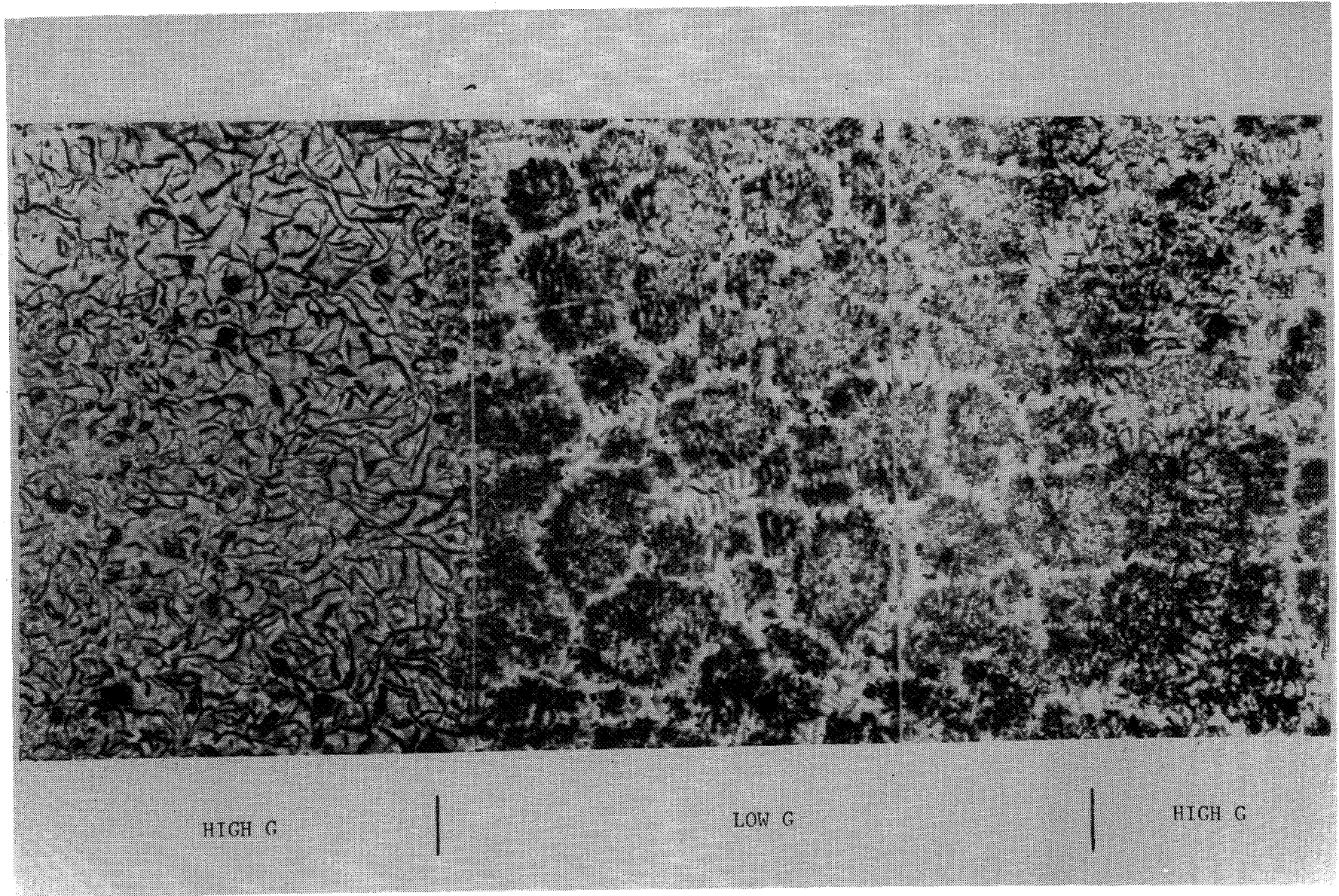
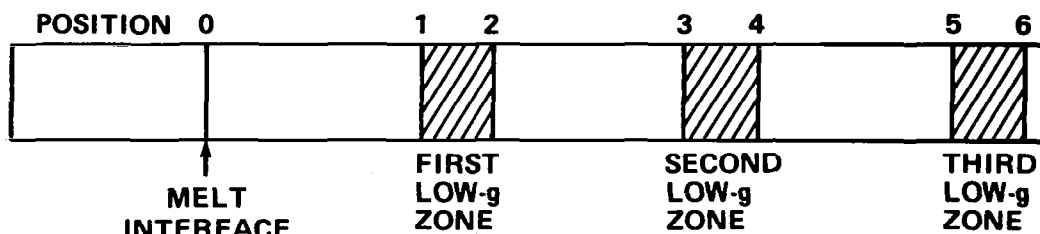


Figure 12. Transition from planar solidification (type A graphite) to irregular solidification (type D graphite) at a high-g to low-g transition on high phosphorus flight sample (Figure 10, top), Nital etched, x 50.

TABLE 1



STOKES' LAW GIVES: 
$$v = \frac{2}{9} r^2 (\gamma_2 - \gamma_1) \frac{g}{\eta}$$

- WHERE
- v : FLOTATION RATE, cm/sec
  - r : RADIUS OF SPHERICAL PARTICLE, cm
  - $\gamma_2$  : DENSITY OF THE LIQUID, g/cm<sup>3</sup>
  - $\gamma_1$  : DENSITY OF THE PARTICLE, g/cm<sup>3</sup>
  - g : ACCELERATION DUE TO GRAVITY, cm/sec<sup>2</sup>
  - $\eta$  : VISCOSITY OF THE LIQUID, CENTIPOISE

THE FOLLOWING VALUES WERE USED FOR CALCULATIONS:

- r = 0.00045 cm FOR THE RADIUS OF SG NODULES ON FIGURE 18
- $\gamma_2$  = 7 g/cm<sup>3</sup> FOR THE DENSITY OF CAST IRON
- $\gamma_1$  = 2.25 g/cm<sup>3</sup> FOR THE DENSITY OF GRAPHITE
- g = DIFFERENT VALUES CORRESPONDING TO DIFFERENT ZONES (SEE FOLLOWING TABLE)
- $\eta$  = 0.078 CENTIPOISE FROM REFERENCE (13)

TABLE WITH VALUES FOR THE GROWTH RATE R, ZONE LENGTH d, ACCELERATION DUE TO GRAVITY g AT VARIOUS POSITIONS ALONG THE SAMPLE:

POSITION	R, cm/sec	d, cm	g, cm/sec <sup>2</sup>
1	R <sub>01</sub> = 0.1055	d <sub>01</sub> = 0.95	g <sub>01</sub> = 1.49 x 981
2	R <sub>12</sub> = 0.0032	d <sub>12</sub> = 0.055	g <sub>12</sub> = 0
3	R <sub>23</sub> = 0.0032	d <sub>23</sub> = 0.12	g <sub>23</sub> = 1.32 x 981
4	R <sub>34</sub> = 0.0032	d <sub>34</sub> = 0.093	g <sub>34</sub> = 0
5	R <sub>45</sub> = 0.0032	d <sub>45</sub> = 0.161	g <sub>45</sub> = 1.24 x 981
6	R <sub>56</sub> = 0.0032	d <sub>56</sub> = 0.093	g <sub>56</sub> = 0

## PROJECT EXPLORER

by

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and

Experiment No. 1: Arthur Henderson, Clarkson College, N.Y.  
Experiment No. 2: Jonathan Lee, University of Alabama, Huntsville  
Experiment No. 3: Guy Smith, Johnson Environmental Center – UAH  
Experiment No. 4: Ed Stluka, Marshall Amateur Radio Club, Huntsville

### ABSTRACT

PROJECT EXPLORER is a program that will fly student-developed experiments onboard the Space Shuttle in NASA's "Get-Away Special" (GAS) containers. The program is co-sponsored by the Alabama Space and Rocket Center, the Alabama-Mississippi Section of the American Institute of Aeronautics and Astronautics, Alabama A&M University and requires extensive support by the University of Alabama in Huntsville. A unique feature of this project will demonstrate transmissions to ground stations on amateur radio frequencies in English language.

Experiment Nos. 1, 2, and 3 use the microgravity of space flight to study the solidification of lead-antimony and aluminum-copper alloys, the growth of potassium-tetracyanoplatinate hydrate crystals in an aqueous solution, and the germination of radish seeds. Flight results will be compared with Earth-based data.

Experiment No. 4 features radio transmissions and will also provide timing for the start of all other experiments. A microprocessor will obtain real-time data from all experiments as well as temperature and pressure measurements taken inside the canister. These data will be transmitted on previously announced amateur radio frequencies after they have been converted into the "English language" by a digitalker for general reception.

# CONTAINERLESS DROP TUBE SOLIDIFICATION AND GRAIN REFINEMENT OF NiAl<sub>3</sub>

by

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## INTRODUCTION

The present study was undertaken in order to investigate the possibility of undercooling Ni-Al alloys below the liquidus in order to produce a single phase peritectic structure by containerless drop tube solidification (Figure 1). Containerless processing is a technique for both high purity contamination free studies as well as for investigating the undercooling and rapid solidification of alloys by suppression of heterogeneous nucleation on container walls. In order to achieve large undercoolings one must avoid heterogeneous nucleation of crystallization. It has been shown that the Marshall Space Flight Center drop tubes are unique facilities for containerless solidification experiments and large undercoolings are possible with some alloys (Lacy et al., 1981; Robinson 1981).

Nickel alloys rich in Al are used as Raney catalyst materials. In general, Raney alloys consist of two metallic components, one of which is a catalytically active transition metal such as Ni. Upon reacting the Ni-Al alloy with caustic aqueous solution, the Al atoms preferentially leach out of the alloy leaving behind an ultra high surface area Ni sponge. The sponge is catalytically active and is used for a number of chemical reactions such as the methanation of hydrogen and carbon monoxide to methane and water (Baird and Steffgen 1977), the steam re-formation of hydrocarbons, and hydrogenation reactions (Fasman et al., 1972; Oden et al., 1977; O'Hare and Mauser 1977; Stiles 1971).

The objective of this work was to containerlessly solidify samples of an Ni-Al alloy with a composition close to that of the compound NiAl<sub>3</sub>. It has been demonstrated that the NiAl<sub>3</sub> eta phase is catalytically the most active component of a Raney type alloy (Petrov et al., 1969; Baird and Steffgen 1977) such that the overall activity of Raney Ni depends mainly on the NiAl<sub>3</sub> phase content of the alloy (Fasman et al., 1972). The desired result was the formation of a high percentage of the NiAl<sub>3</sub> compound with minimal amounts of the other surrounding compounds Ni<sub>2</sub>Al<sub>3</sub> (delta phase) and Al solid solution.

## EXPERIMENTAL PROCEDURE

The Marshall Space Flight Center 30-meter drop tube was used to process the samples for this study (Figure 2). The drop tube consists of a 6 in. diameter welded stainless steel tube with turbomolecular pumping ports on the top and bottom levels. At the top is a connection for a vacuum feedthrough ring and bell jar into which sample processing equipment is placed. At the bottom is a sample catcher that is used to remove samples that have solidified in freefall down the tube. The system is designed to operate either in a vacuum (i.e.,  $10^{-5}$  torr) or in an inert atmosphere. For these experiments we used an atmosphere of He with 6%H at slightly greater than one atmosphere pressure.

Premelted samples of the alloy were placed into an alumina crucible and inserted into the furnace shown in Figure 3. A pneumatic gas line was attached to the crucible to provide a back pressure used to eject molten sample drops from a small orifice in the bottom of the crucible. We found that a difference in pressure between the bell jar and the crucible of 20 mm Hg was sufficient to extrude a number of molten drops out of the crucible.

## RESULTS

Figure 4 shows scanning electron micrographs of three different size drops solidified in containerless conditions. One could see dendrites on the surface of all of the samples. Also there is a noticeable large difference in scale of the microstructural features with the different size samples.

Light micrographs of the samples also show that there is a strong influence of sample size on microstructural features (Figure 5). Also in Figure 5 one can see that the same types of phases are present in all three sizes of samples. Figure 6 identifies the phases present in the microstructure. The microstructure of all of the samples is similar to that of traditionally solidified alloy. The first phase to solidify is the  $\text{Ni}_2\text{Al}_3$  phase. Normally it solidifies when the liquidus temperature is reached and continues to solidify until the peritectic temperature is reached. At the peritectic temperature the  $\text{NiAl}_3$  phase begins to solidify and continues until the eutectic temperature is achieved. At the eutectic, the remaining liquid solidifies as a eutectic mixture of  $\text{NiAl}_3$  and Al. Except for the size of the features, the microstructure for the crucible solidified sample in Figure 6 is very similar to the containerlessly solidified samples in Figure 5.

## DISCUSSION

In spite of the large undercoolings and unique microstructures achieved in other studies utilizing the MSFC drop tube, we did not see this with the  $\text{NiAl}_3$  alloy. In other micrographs the spacings of the dendrite arms indicate that the dendrites nucleated at the surface and grew through the sample. Since the vapor pressure of oxygen in the atmosphere was not zero, some surface oxidation in the form of  $\text{Al}_2\text{O}_3$  would always be present. Other studies have postulated that  $\text{Al}_2\text{O}_3$  is a strong surface nucleant for melts containing Al (Turnbull and Cech 1950). These results indicate that even in the absence of containers during solidification, surface heterogeneous nucleation may result from the reaction of some melts with gases in the surrounding atmosphere.

Another interesting observation, however, was made. The microstructural feature separation is a strong function of sample size. More accurately the microstructure is a function of cooling rate, since the sample size determines the cooling rate. In Figure 7 the relation between dendrite arm spacing (DAS) and cooling rate as published by Brooks *et al.* (1982) is shown. On this line we have superimposed data from the present study. This data illustrates that containerless solidification in free fall down the drop tube is another means of achieving rapid solidification and microstructural refinement.

## CONCLUSIONS

Although we were successful with the original goal of undercooling the liquid metal well below the liquidus to the peritectic temperature during containerless free to form primarily NiAl<sub>3</sub>, the microstructures were interesting from another point of view. The microstructure from small diameter samples is greatly refined. Small dendrite arm spacings such as these could greatly facilitate the annealing and solid state transformation of the alloy to nearly 100% NiAl<sub>3</sub> by reducing the distance over which diffusion needs to occur. This could minimize annealing time and might make it economically feasible to produce NiAl<sub>3</sub> alloy.

## ACKNOWLEDGMENTS

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## REFERENCES

- Baird, M. J. and F. W. Steffgen (1977), "Methanation Studies of Nickel-Aluminum Flame Sprayed Catalysts," *Ind. Eng. Chem., Prod. Res. Dev.* 16: 142-147.
- Brooks, C. S., F. D. Lemkey, and G. S. Golden (1982), "Fibrous Hydrogenation Catalysts Derived From Ni-Al Eutectic Alloys," *Surface Science* 16: 67-85.
- Brooks, C. S., G. S. Golden, and F. D. Lemkey (1982), "Synthesis of Highly Dispersed Supported Metal Catalysts via Chemical Dissolution and Precipitation of Eutectic Alloys," *Surface Technology* 11: 333-347.
- Brooks, C. S., F. D. Lemkey, and G. S. Golden (1982), "Rainey Type Catalysts From RSA Atomization of Al-Ni Powders," in *Rapidly Solidified Amorphous and Crystalline Alloys*, pp. 397-407, eds. B. H. Kear, B. C. Giessen and M. Cohen, Elsevier Press, N. Y.
- Fasman, A. B., V. F. Timofeeva, V. N. Rechkin, Yu. F. Klyucnikov and I. A. Sapukov (1972), "Effect of Composition of a Nickel-Aluminum Alloy on the Structure and Specific Activity of a Raney Nickel Catalyst," *Kinetics and Catalysis (USSR)*, 13: 1347-1352.
- Lacy, L. L., M. B. Robinson, and T. J. Ratz (1981), "Containerless Undercooling and Solidification in Drop Tubes," *J. Crys. Growth*, 51: 47-60.



- Oden, L., P. Sanker, and J. H. Russell (1977), U. S. Patent 4,049,580.
- O'Hare and J. E. Mauser (1977), Bureau of Mines Report No. 8210.
- Petrov, B. E., N. V. Cherkashina, A. B. Fasman, D. V. Sokolskii, E. N. Lebedeva, and B. P. Baraovashina (1969), Kinet. Katal. 10: 1146.
- Robinson, M. B. (1981), "Undercooling Measurement in a Low-Gravity Containerless Environment," M. S. Thesis, U. of Alabama, Huntsville.
- Stiles, Alvin B. (1971), U. S. Patent 3,627,790.
- Turnbull, D. and R. E. Cech (1950), "Microscopic Observation of the Solidification of Small Metal Droplets," J. Appl. Phys. 21: 804-810.
- Willey, L. A. (1967), "Appendix 1. Phase Diagrams," in Aluminum – Volume I, pp. 359-381, K. R. Van Horn, ed., and Metals Handbook – Vol. 8, p. 262, Am. Soc. for Metals.

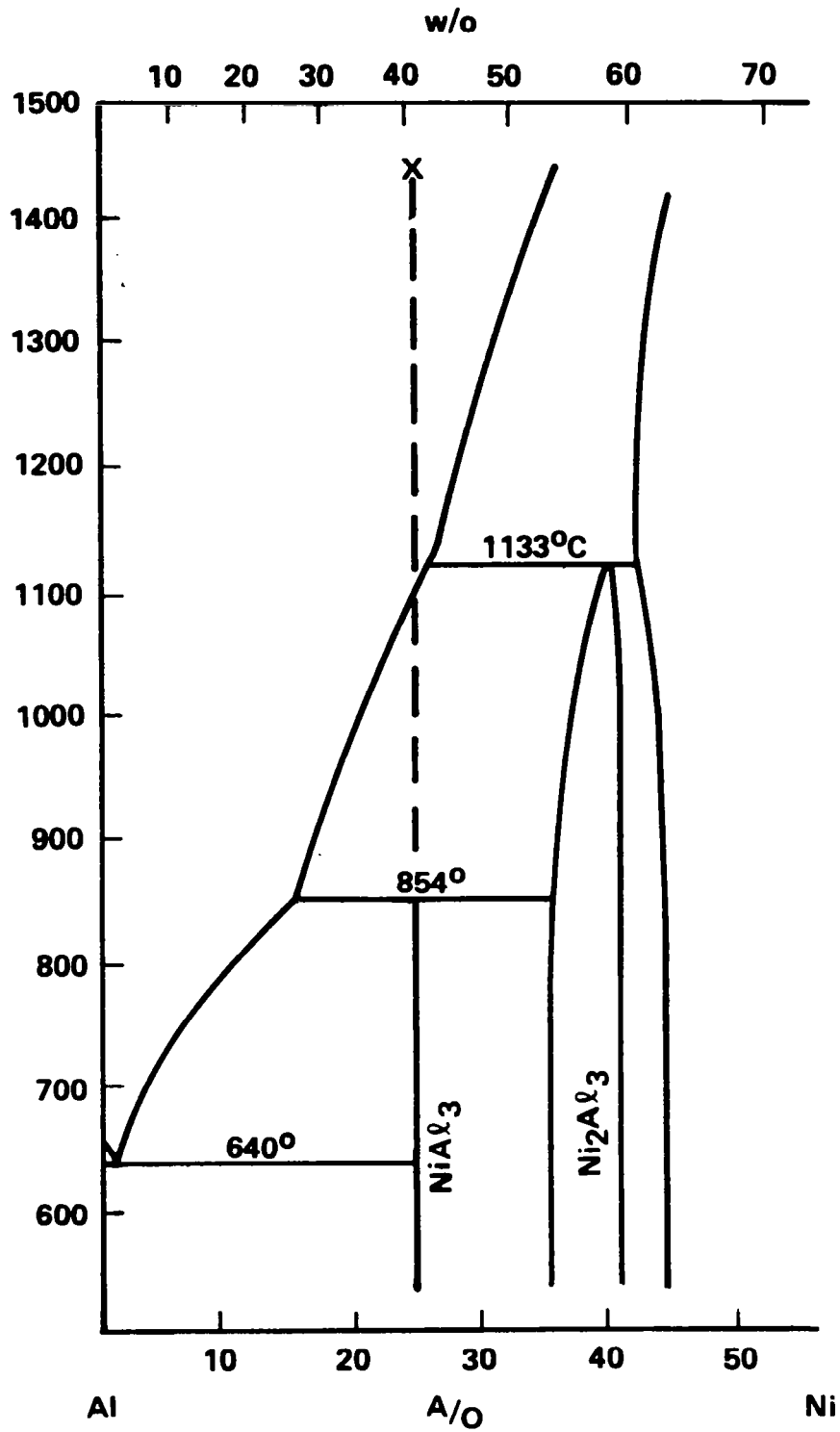


Figure 1. Phase diagram for the Al rich side of the Ni-Al alloy system, after Wiley (1967).

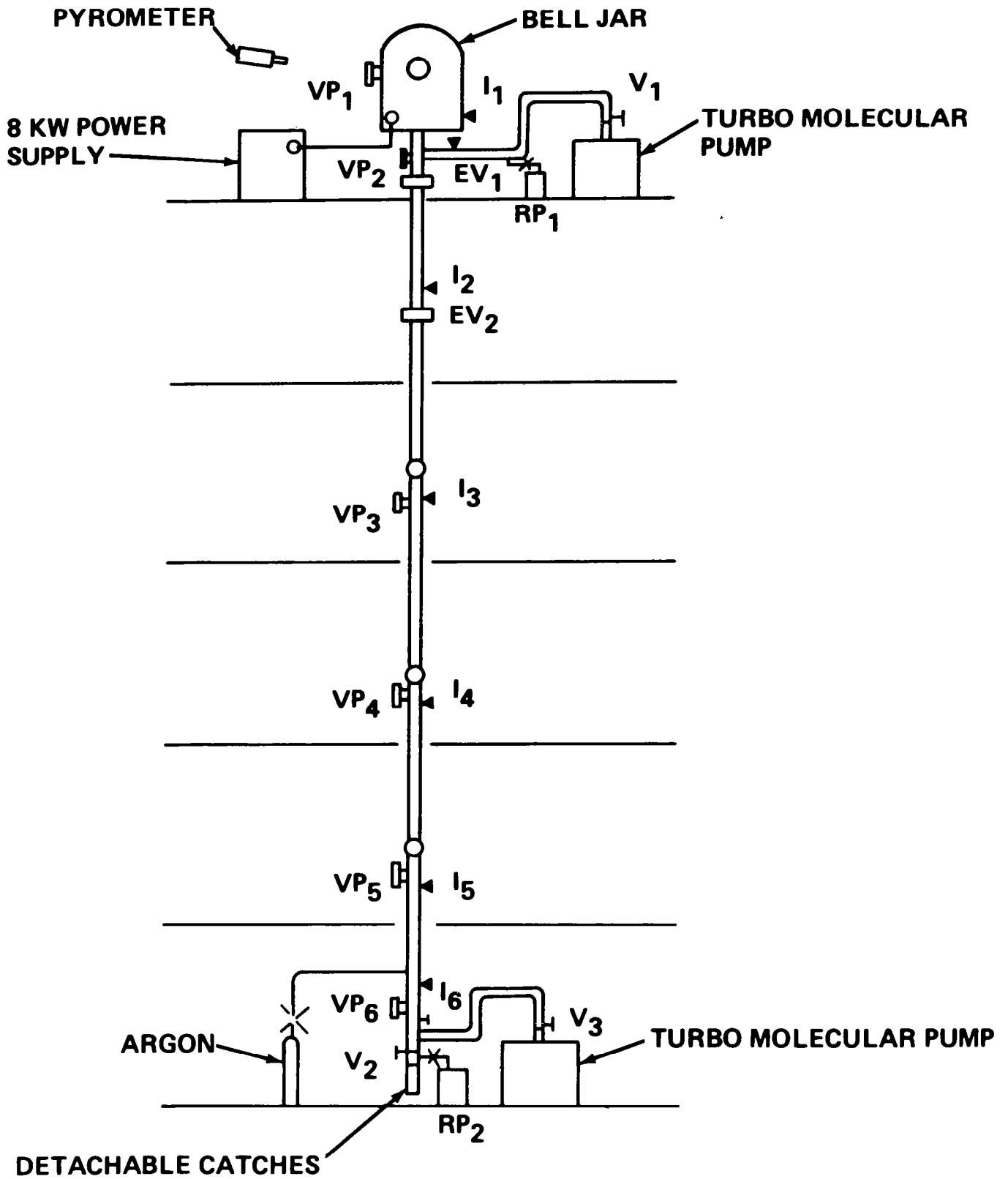


Figure 2. Schematic diagram of the 30-meter drop tube at the Marshall Space Flight Center.

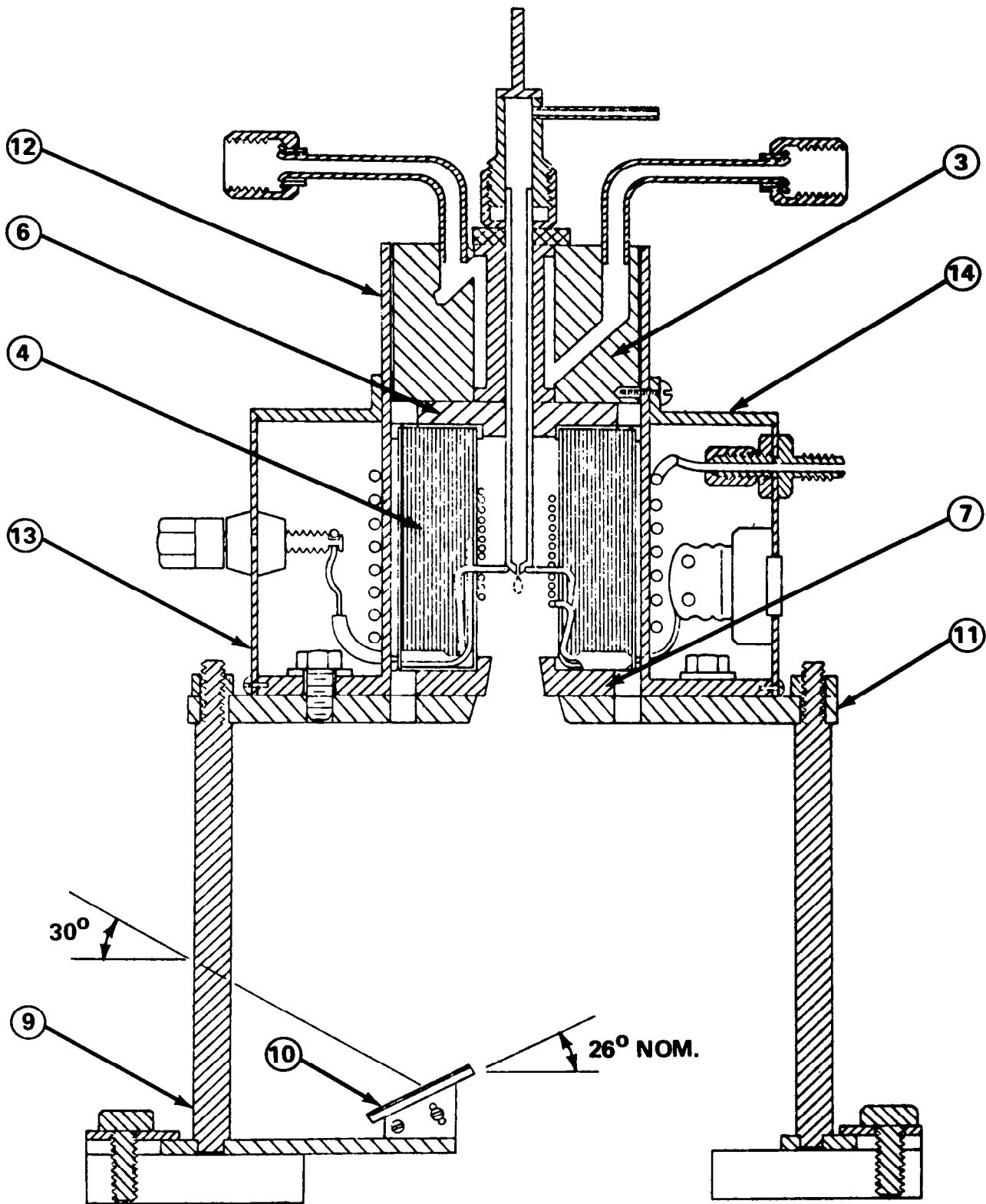


Figure 3. Schematic diagram of the furnace used to melt and process the alloy samples for the drop tube experiments.

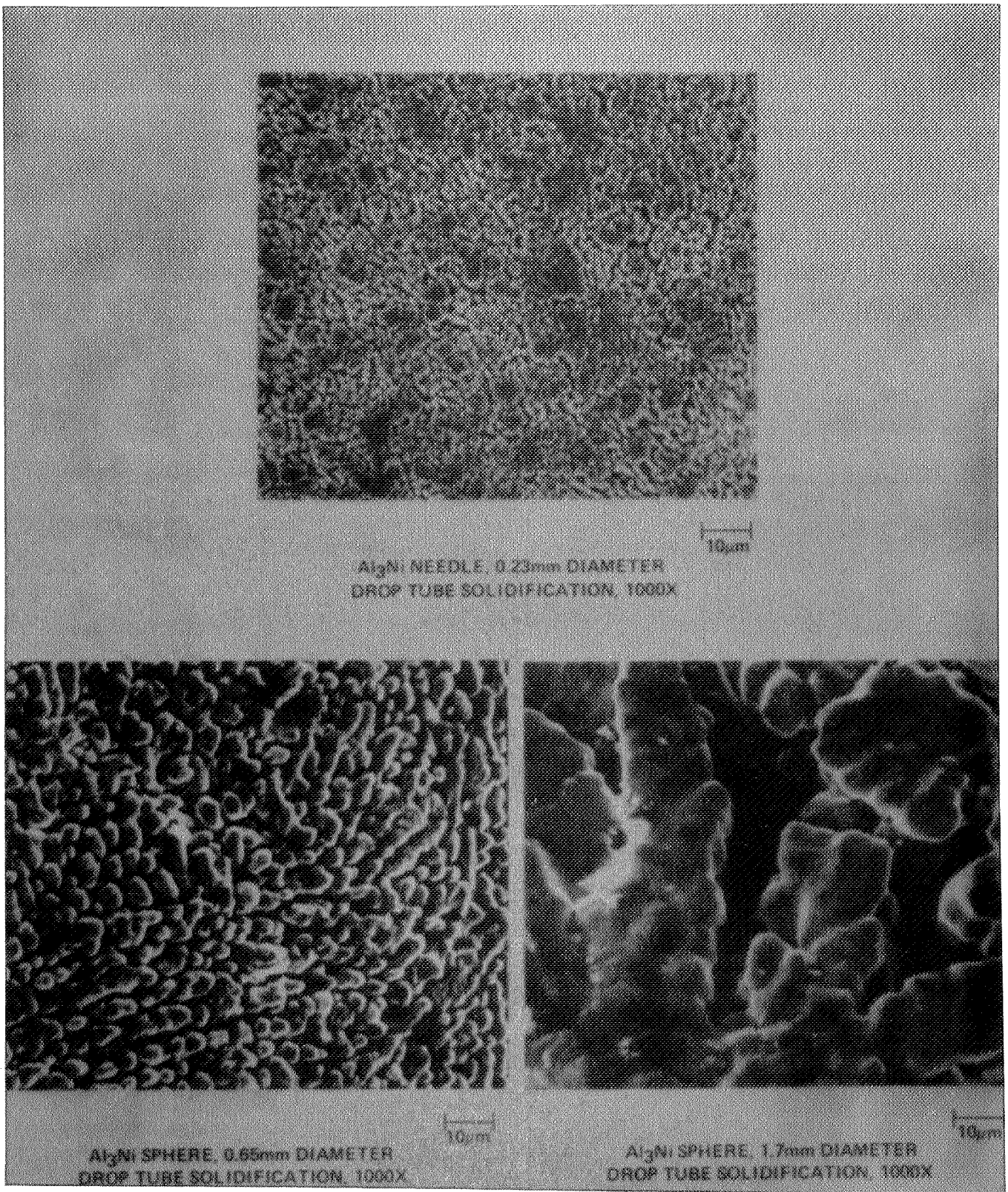


Figure 4. Scanning electron micrographs of containerlessly solidified spherical samples.

CONTAINERLESS SOLIDIFICATION OF  $\text{NiAl}_3$   
ORIGINAL MAGNIFICATION 1350X  
1 cm = 7.4  $\mu\text{m}$

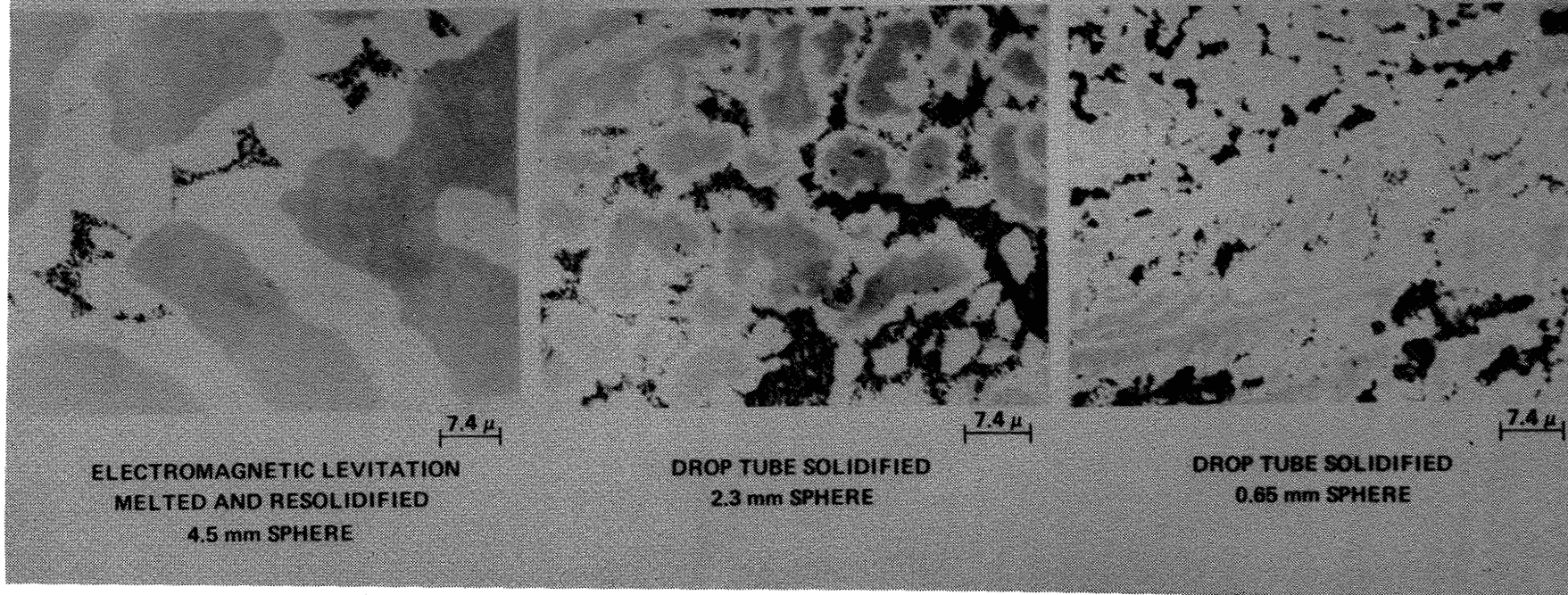


Figure 5. Light micrographs of samples of various diameters.

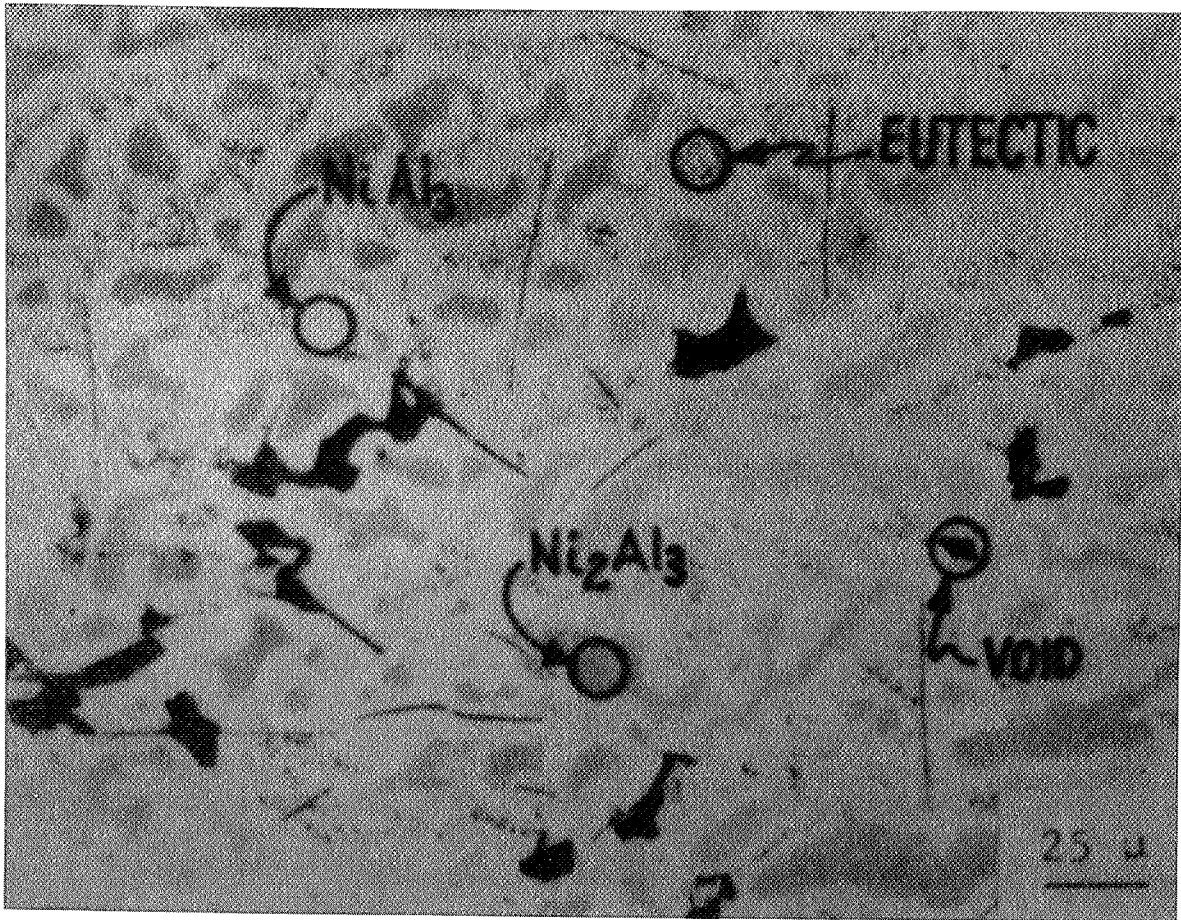


Figure 6. Light micrograph of a traditionally solidified sample illustrating the phases present.

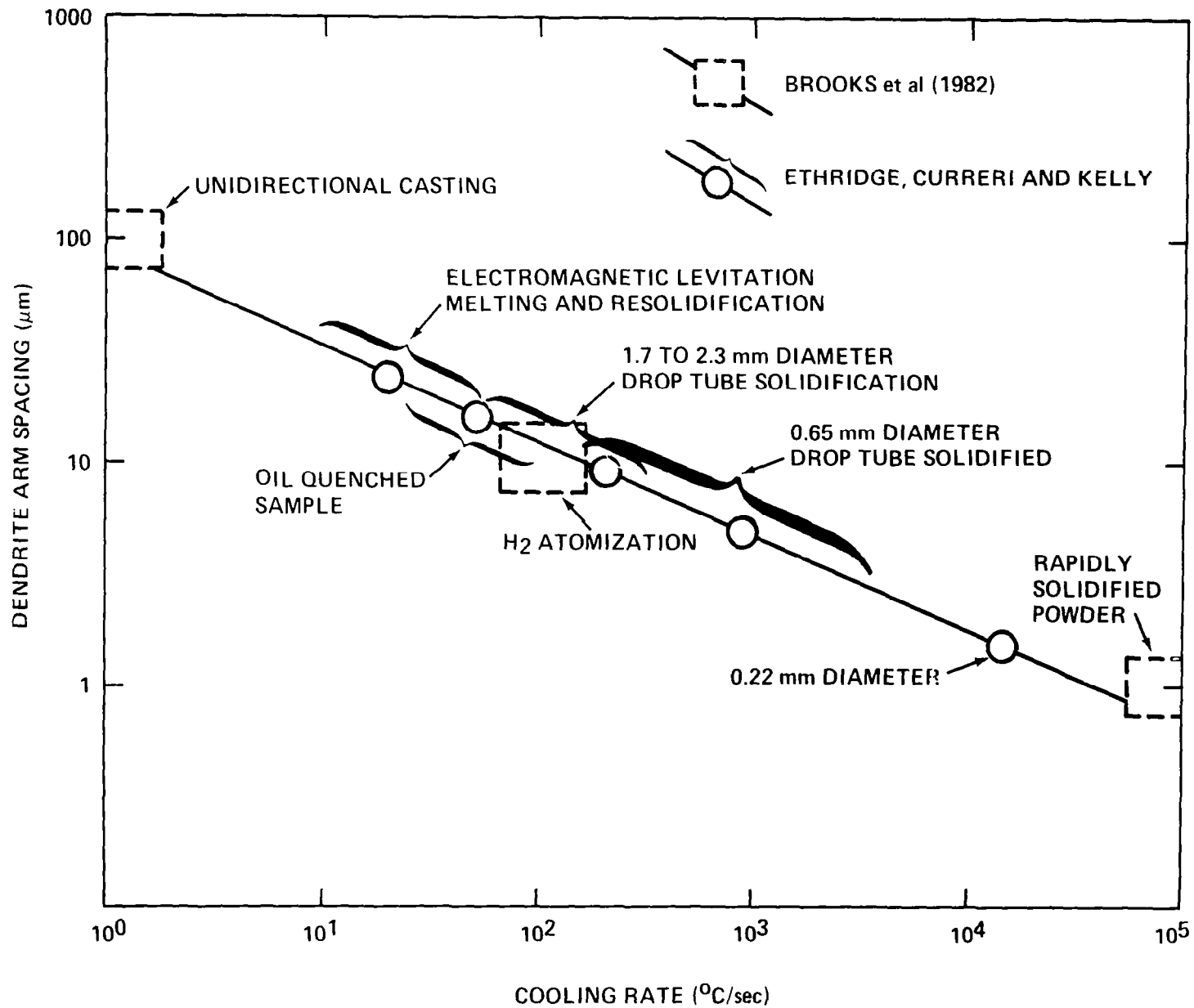


Figure 7. A plot of the Dendrite Arm Spacing (DAS) of  $\text{NiAl}_3$  samples as a function of sample cooling rate.



## PURIFICATION OF BIOMATERIALS BY PHASE PARTITIONING

by

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### ABSTRACT

There has been much recent interest in the purification of biomaterials (proteins, cells) by electrophoresis in microgravity. Another technique which is particularly suited to this environment and which is potentially more powerful than electrophoresis is phase partitioning. Phase partitioning is purification by partitioning between the two immiscible aqueous layers formed by solution of the polymers poly(ethylene glycol) and dextran in water. This technique has proven to be very useful for separations in one-g but is limited for cells because the cells are more dense than the phase solutions and thus tend to sediment to the bottom of the container before reaching equilibrium with the preferred phase.

There are three phases to our work in this area: (1) synthesis of new polymers for affinity phase partitioning; (2) development of automated apparatus for ground-based separations; and (3) design of apparatus for performing simple phase partitioning space experiments, including examination of mechanisms for separating phases in the absence of gravity.

## DEVELOPING COMMERCIAL USERS OF SPACE

by

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### ABSTRACT

Until recently space has offered the scientific and communications industry a platform to study the universe, evaluate the environment, observe Earth and provide a vantage point for broadcast coverage. With the routine flights of the Space Shuttle a direct use of the space environment, namely low gravity, has become available for scientific and commercial utilization. Although understood by the aerospace community it is not well known within the commercial establishment.

It has been our objective to stimulate, assist and help develop a community of commercial users of space, who will in future years, become proponents of a Space Station and or space laboratories.

The development of this user requires re-education at the technical and management levels to describe the benefits afforded by low gravity and how this phenomena may be used to make new products or increase present performance levels.

Our presentation material shown on the poster elucidates the low gravity fundamentals clearly and simply. A display of past low gravity experiments highlights some of these precepts which are followed by a description of where and how the commercial user can fly his experiment or process. The conscious growth from a Space Shuttle to a platform and Space Station provides the commercial companies the long term space commitment required to attract serious interest in space ventures.

The team of Coopers and Lybrand and Grumman will be available to brief non-aerospace commercial companies on the potentials of doing business in space.

# CRITICAL POINT WETTING DROP TOWER EXPERIMENT

by

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and

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University of Alabama in Huntsville  
Huntsville, Alabama 35486

## ABSTRACT

The theory of Critical Point Wetting (CPW) by John Cahn (NBS) was recently proposed (1976) to explain the unusual and unexpected behavior between two immiscible fluids near their critical temperature. Little experimental evidence is available to support the theory. In this series of drop tower experiments, the theory is tested for two-liquid immiscibles. The drop tower provides the low-g environment required to allow surface tension forces to overcome hydrostatic forces generated by the density differences between the two fluid phases in Earth gravity. The theory is proven if the wetting transition temperature can be found. An abrupt change in wetting behavior occurs at this special temperature. It should be possible to find the transition temperature by using several drops over a range of temperatures up to critical temperature.

The second aspect of the experiment utilizes the drop tower as a measurement tool for determining the interfacial free energies (IFE) between two fluids in near-critical systems. Successful drops with different temperatures will give the very important temperature dependence of the IFE. The oscillation frequency depends on the change in acceleration, which for the drop tower can cover five orders of magnitude. By measuring the oscillation of the interface caused by the drop, the IFE may be determined at temperatures close to critical.

The IFE measurements from the tower, together with other IFE data should permit calculation of the wetting transition temperature from the CPW theory.

## INTRODUCTION

Wetting phenomena and other fluid behavior can be observed in a microgravity environment by using the MSFC Drop Tower. This facility is being used to test the critical point wetting (CPW) theory of Cahn [1]. Early results of a preliminary feasibility study are the topic of this paper. In this test, transparent binary solutions which form two liquid phases in a monotectic (immiscible) system are used. The shape of the meniscus formed between these two liquid phases contained in an upright cylindrical tube was photographed as the sample experienced the transition from 1 g (at the top of the tower), to approximately  $10^{-5}$  g during the free fall. The

meniscus shape changes in response to the acceleration change because of the density difference between the two phases. With the removal of Earth gravity, the forces acting on the interface are solely determined by the balance of interfacial energies (or tensions) between the three phases: liquid 1, liquid 2, and the solid container wall. It is the individual variations of these interfacial energies with temperature that lead to the CPW behavior that is expected to occur. A number of drops, each at a different temperature should reveal the critical wetting transition temperature which should be found somewhat below the critical temperature for the system in question.

The considerable significance of such experiments can be attributed to their fundamental nature. Aspects of studies in crystal growth, nucleation phenomena, solidification of monotectics, superfluidity phenomena, cryogenic liquid storage problems, thin liquid films, and in undercooling of immiscible alloys concern CPW theory [2-7].

## EXPERIMENT APPARATUS

The experiment package consists of a circulating water bath, high speed motion picture camera (500 frames per sec. Milliken), lights, batteries, temperature controller and digital timer. Specimen capsules were mounted in the bath cannister in such a way that the camera sees the back-lighted specimen interfaces through the bath window (see Figure 1). Figure 2 shows the optical path in profile view. Figure 3 is the actual set-up shown previously in Figure 2. An idea of the overall dimensions of the experiment can be obtained from Figure 4 which shows M. Tcherneshoff and S. Straits from the University of Alabama in Huntsville working on the package.

The specimens themselves are flame-sealed glass ampoules. The interfaces will be axisymmetric within these cylindrical tubes. The tube axis is oriented parallel with the gravity vector, i.e., up-down. This orientation provides the proper geometry for interface shape analysis.

The two-liquid phase systems which are possible candidates for testing are succinonitrile- $H_2O$ , succinonitrile-ethanol, cyclohexane-methanol, and diethylene glycol-ethyl salicylate. The later two systems already have some interfacial energy data available [8,9]. These systems all have consolute solution temperatures above room temperature but below the boiling point of water. This facilitates temperature control and maintenance of safety.

The experiment package, Figure 4, sits inside the drop tower dragshield for the duration of the test drop. The dragshield is shown in Figure 5. The drop height is 100 meters and a high pressure gas rocket nozzle on top of the shield helps keep the package accelerating with the rate:  $g$ , despite air resistance. Upon release, the thruster pushes the shield down from under the package inside. From that moment on, the package falls free of outside interference and experiences minimal  $g$ -forces in all three axis. Potentially superior low- $g$  levels can be obtained over that experienced in the KC-135 airplane during Keplerian flight. The cost per unit time of low- $g$  is lower as well. Up to 4 seconds of low- $g$  can be obtained with the drop tower. Turn around time on the tower can be as little as one hour per drop.

Drop towers have been used for low- $g$  fluids experiments in the past [10-14]. The facility at MSFC was constructed to study the behavior of rocket propellants within fuel tanks in order to ensure reliable fuel and oxidant flow to the engine. The facility is now dedicated to the performance of materials science experiments in low- $g$ .

Oscillations of the fluid in the tank models mentioned above, were observed and the behavior of the fluid was determined to be dependent on the interfacial energy (surface tension) of the fluid-vapor interface. The period of oscillation for the given geometry and liquid combination varied with surface tension. This very behavior is useful to measure the (unknown) surface energy of a fluid as a function of temperature. This technique almost requires a drop tower type of facility. It is the sudden unloading of the pull of gravity which sets the interface into motion. The restoring force of the surface tension causes the interface to change shape to accommodate the new balance of forces since the hydrostatic forces caused by the density differences of the two fluid phases (in that case, vapor and liquid) were removed [11]. Although damped by fluid viscosity, the interface acts like a taut skin and oscillates like a weight on a spring.

## INTERFACE SHAPES

These drop tower experiments involve the study of interphase interfaces from the motion picture film taken during the drop. It should be possible to measure the interfacial free energy and to determine the wetting transition temperature for the CPW theory from the film or a series of films from drops performed at various temperatures. The static interface shape can be calculated using the Bond number,  $B_o$ :

$$B_o = \Delta\rho\alpha r^2/\sigma_{1v}$$

where  $\Delta\rho$  is the density difference between the liquid phases,  $\alpha$  is the acceleration level,  $r$  is the tube radius, and  $\sigma_{1v}$  is the surface tension of the interface. Figure 6 shows calculated interface shapes for some systems with the contact angle fixed at 5 degrees, the tube diameter 1 cm and 1 g acceleration. The final interface shape at static equilibrium can be calculated and compared to the interface shape measured in the specimen if the oscillations damp-out. Interfacial energy and/or contact angle measurements are possible from such comparisons.

## PRELIMINARY RESULTS

At the present time, only a couple of successful drops were performed. Figures 7 and 8 are a pair of individual frames taken from the 16-mm film of the latest drop. One frame is that of the specimens in 1 g just before the drop, Figure 7. The other is of the specimens after a 1 sec period of low-g ( $10^{-3}$  g approximately). In the left ampoule is the immiscible system, succinonitrile-ethanol; in the middle ampoule is cyclohexane-methanol; and in the third ampoule is the third immiscible, succinonitrile-water. The center ampoule is 1 cm in diameter. Two interfaces are seen in each ampoule. The uppermost interface is that of the top liquid phase and the vapor, the lower of the two is the interface between the upper and lower liquid phases. The higher surface tension of the liquid-vapor interface causes it to form a near spherical ullage. The low interfacial energy of the left sample is clearly seen by looking at the relative flatness of this interface in 1 g. As expected, this interface curvature increases after the acceleration of gravity is removed. The other interfaces also respond as expected, for example, the right hand sample increases its interfacial curvature dramatically in low-g. Note how the different refractive indices of the liquid phases change the spacing of the reference grid lines on either side of the interfaces. The response to the unloading of gravity was different at another temperature.

At this time, no test of the CPW theory has been made. However, some experimental evidence for this theory can be found in the literature [15-18]. This experiment will be the first to use the drop tower to test the CPW theory. A brief explanation of the theory is given in the Appendix.

## CONCLUSIONS

Preliminary results for the CPW Drop Tower Experiment have been produced with immiscible systems. Much of the observed phenomena conformed to the anticipated behavior. More drops will be needed to test the CPW theory with these immiscible systems.

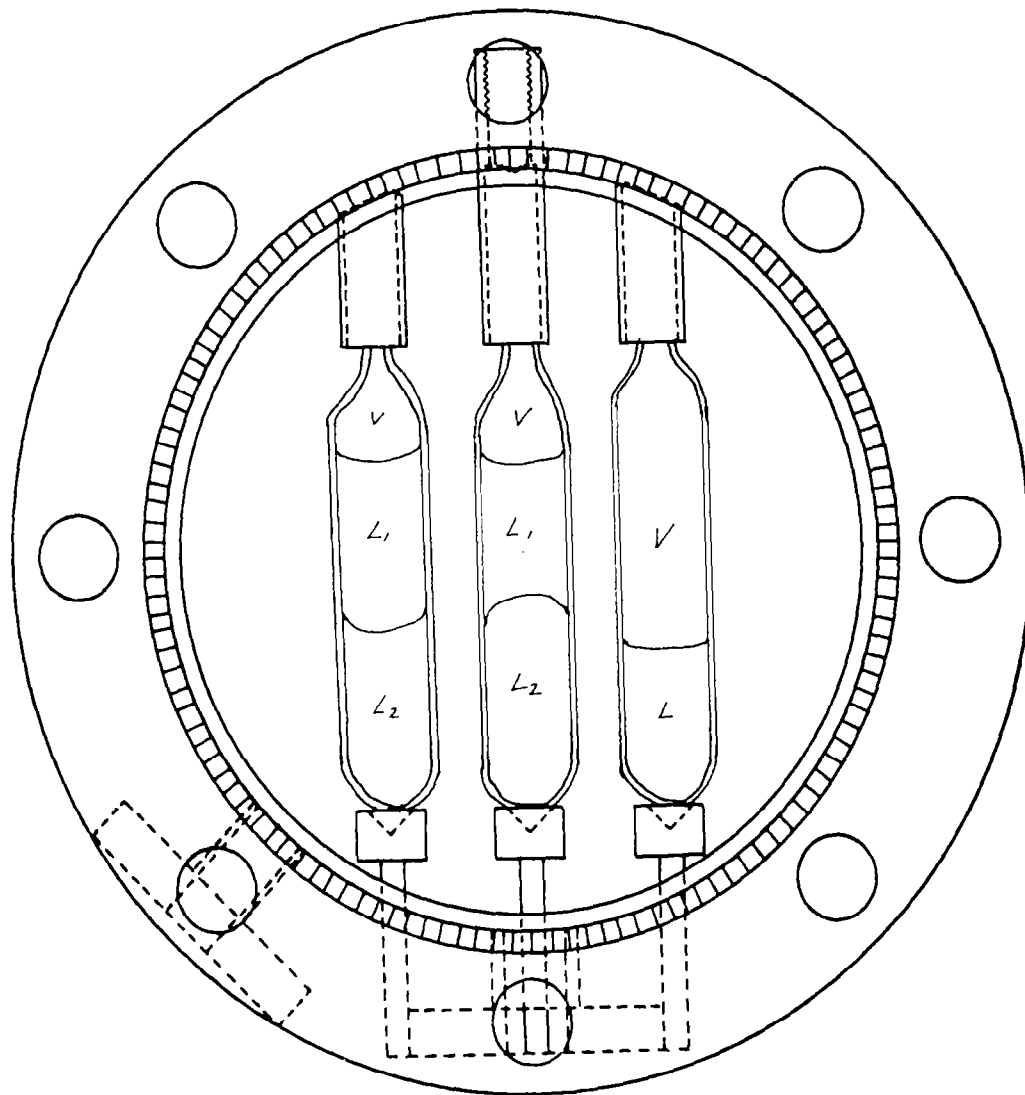
## APPENDIX: CRITICAL POINT WETTING EXPLAINED

The CPW theory is based on the behavior of the interfacial free energies as a function of temperature of the three interfaces involved (see Fig. A). As one approaches the critical temperature for  $L_1$  and  $L_2$ , there is a rapid change in interfacial free energy for each interface as shown [1,7]. The plotted variation of interfacial free energy with temperature is based on the theoretical behavior for such interfaces.

One finds that at the transition temperature,  $T_w$ , the interfacial free energy for the  $L_1L_2$  interphase interface drops more rapidly with temperature than the difference of the interfacial free energies between the liquid phases and the container (third phase). Therefore, at temperatures above  $T_w$ , one liquid phase will preferentially wet the container and cause the other phase to separate from the container wall. This is a direct consequence of the imbalance of the Young equation at temperatures above  $T_w$  and below  $T_c$ . The relative wetting characteristics between the three phases will therefore be sharply altered when the temperature is between  $T_w$  and  $T_c$ . In theory, the two fluid phases may be either those of an immiscible liquid system or of a single component, liquid-vapor system.

## REFERENCES

1. Cahn, J. W., "Critical Point Wetting," J. Chem. Phys. 66, 3667 (April 1977).
2. Moldover, M. R. and Cahn, J. W., Science 207, 1073 (1980).
3. Grugel, R. N. and Hellowell, A., Met. Trans. A. 12A, 669 (1981).
4. Moldover, M. R., Solidification Working Group Meeting, NASA MPS Program, August 24-26, 1982, Washington, D.C.
5. Hellowell, A., Solidification Working Group Meeting, NASA MPS Program, August 24-26, 1982, Washington, D.C.
6. Grugel, R. N. and Hellowell, A., Mat. Res. Soc. Sym. Proc. Vol. 9 (1983), p. 417.
7. Perepezko, J. H., Galaup, C., and Cooper, K. P., MRS Proceedings, Volume 9, p. 491, Elsevier/North Holland, 1981.
8. Lacy, L. L., Witherow, W. K., Facemire, B. R., Nishioka, G. M., NASA TM-82494, June 1982.
9. Warren, C. and Webb, W. W., J. Chem. Phys. 50, 3694 (May 1969).
10. Hastings, L. J., NASA TM-53841, June 26, 1969, MSFC.
11. Siegert, C. E., Petrash, D. A., Otto, E. W., NASA TN D-2458, Lewis Research Center, 1964.
12. Wallner, L. E. and Nakanishi, S., NASA TM X-723, Lewis Research Center, August 1963.
13. Shuleikin, V. V., Soviet Physics-Doklady 8, 985 (April 1964).
14. Shuleikin, V. V., Soviet Physics-Doklady 8, 1221 (June 1964).
15. Heady, R. B., "An Experimental Investigation of Nucleation Theory in a Liquid-Liquid Miscibility Gap," Ph.D. Thesis, MIT, 1969.
16. Heady, R. B. and Cahn, J. W., J. Chem. Phys. 58, 896 (1973).
17. Pohl, D. W. and Goldberg, W. I., Phys. Rev. Lett. 48, 1111 (1982).
18. Schmidt, J. W. and Moldover, M. R., submitted to J. Chem. Phys.



CAMERA VIEW OF CIRCULATING OIL BATH  
FOR DROP TOWER EXPERIMENTS ON CPW

Figure 1.



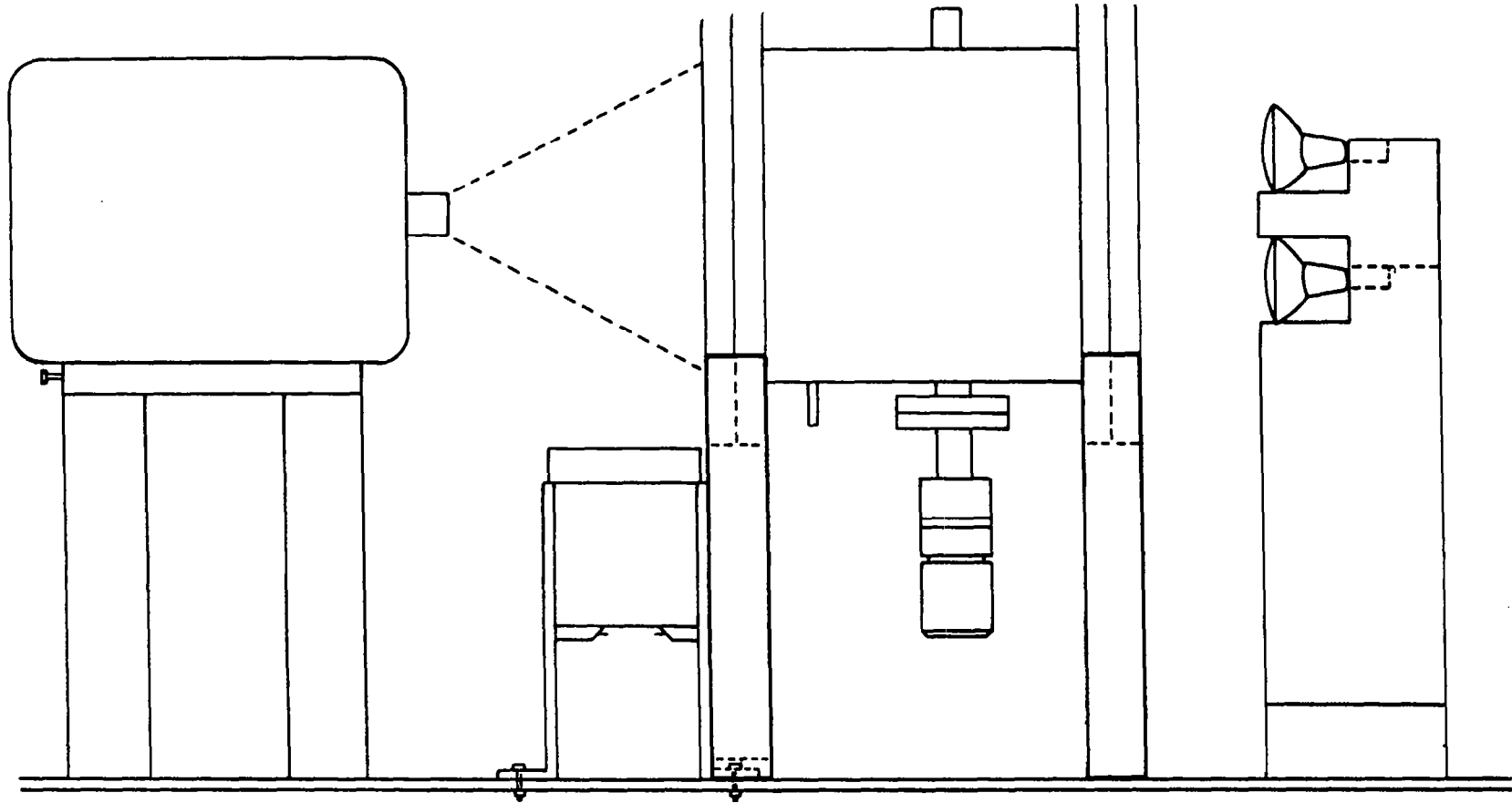


Figure 2. PROFILE VIEW OF EXPERIMENT PACKAGE SHOWING LIGHTS, OIL BATH, CAMERA AND TEMPERATURE CONTROLLER.

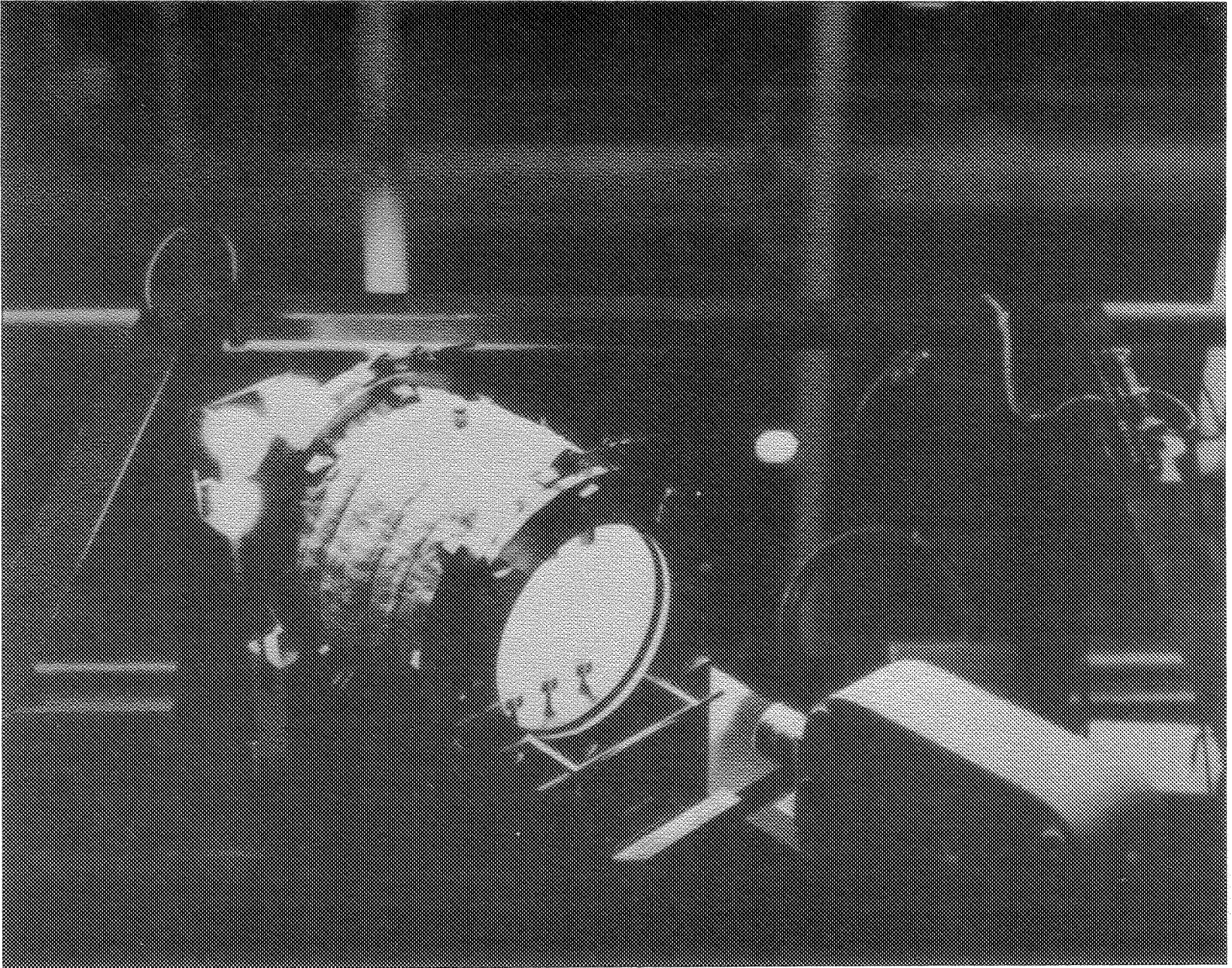


Figure 3

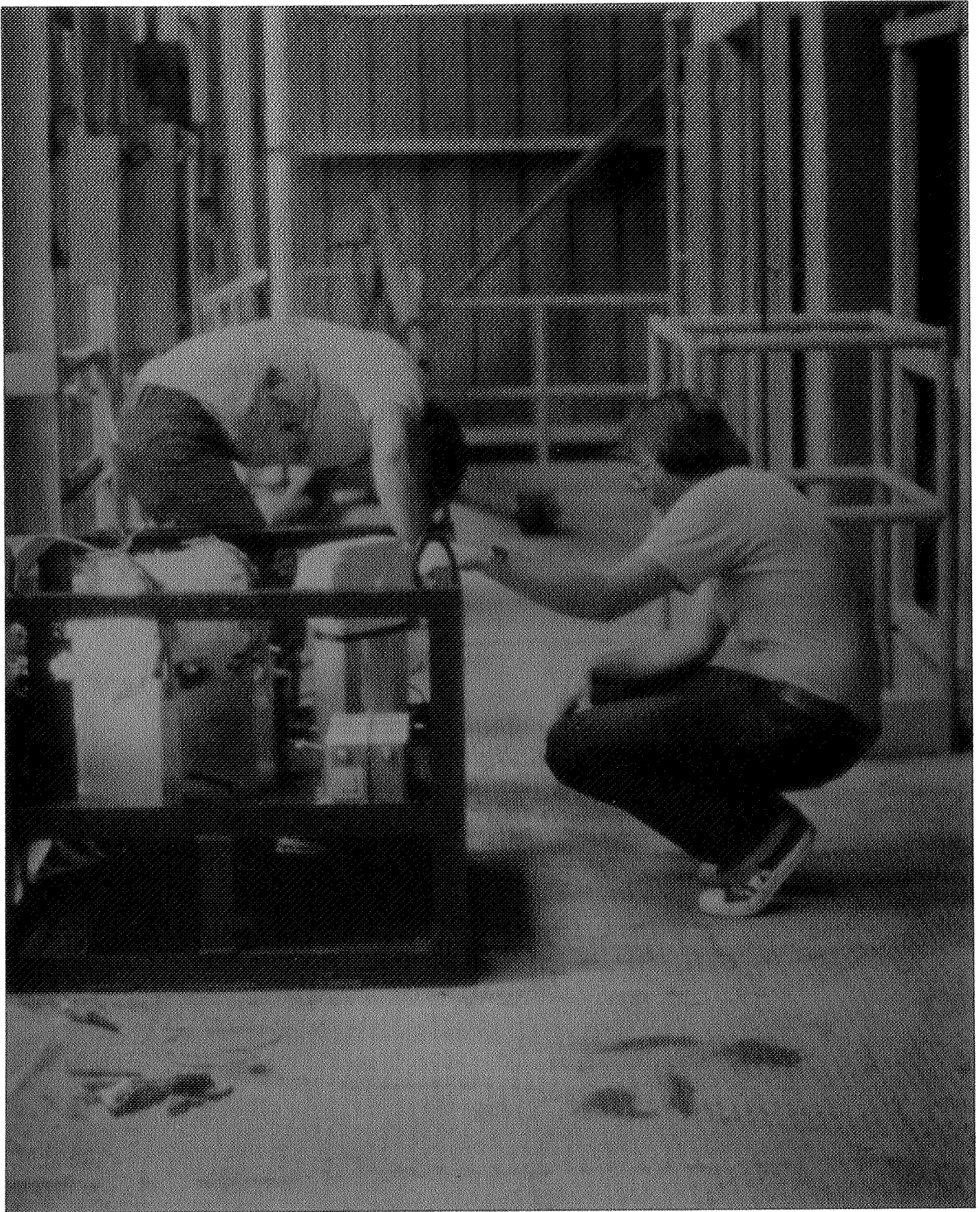
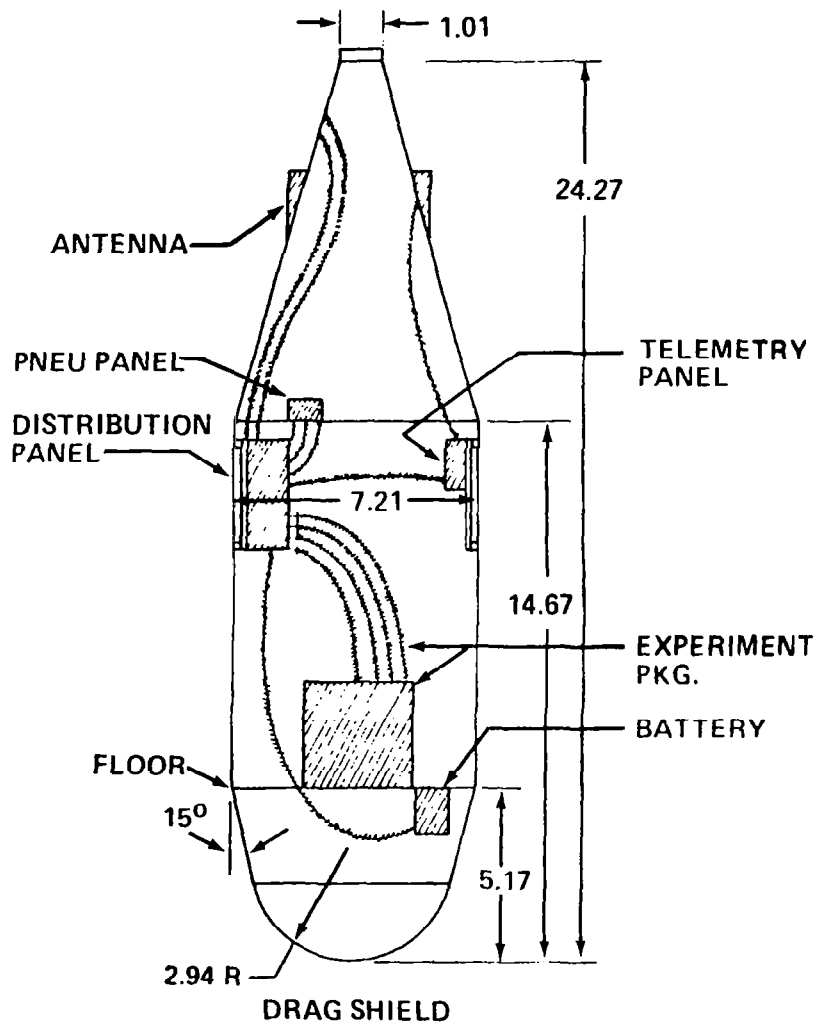


Figure 4



TOTAL DROP HEIGHT 333.8 FT  
 FREE FALL HEIGHT 293.8 FT  
 DRAG SHIELD FREE FALL TIME 4.275 SEC  
 DRAG SHIELD DECELERATION 25 G

**DRAG SHIELD DIMENSIONS:**

LENGTH 24' 3/4"  
 DIA. 7' 2 1/2"  
 WT. 3620 POUNDS  
 TEST AREA 6' X 8'

**PACKAGE SIZE:**

HEIGHT 3 FT  
 WIDTH 3 FT  
 LENGTH 3 FT

MAX TEST PACKAGE WT 450 LBS, MUST BE BALANCED

**LOW GRAVITY RANGE:**

MAX 4 X 10<sup>-2</sup> G  
 MIN 1 X 10<sup>-5</sup> G

AUX DRAG SHIELD THRUST 75 LBS.

Figure 5.

CALCULATED INTERFACE PROFILE FOR VARIOUS BOND NUMBERS. A REPRESENTS THE SUCCINONITRILE AND WATER INTERFACE; B REPRESENTS THE CYCLOHEXANE-METHANOL INTERFACE; C REPRESENTS THE INTERFACE BETWEEN DIETHYLENE GLYCOL AND ETHYL SALICYLATE; ALL AT ROOM TEMPERATURE. D IS FOR COMPARISON

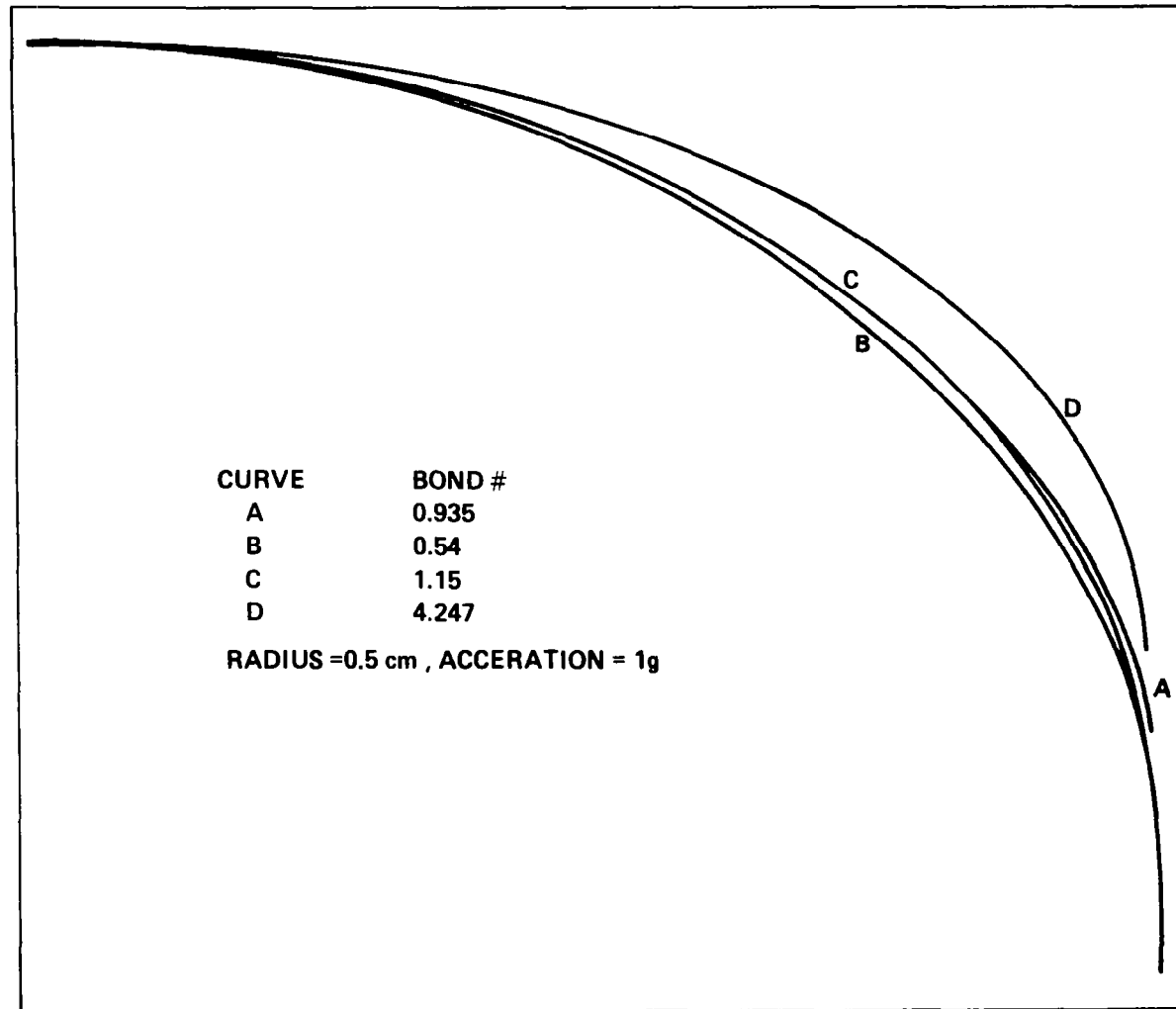
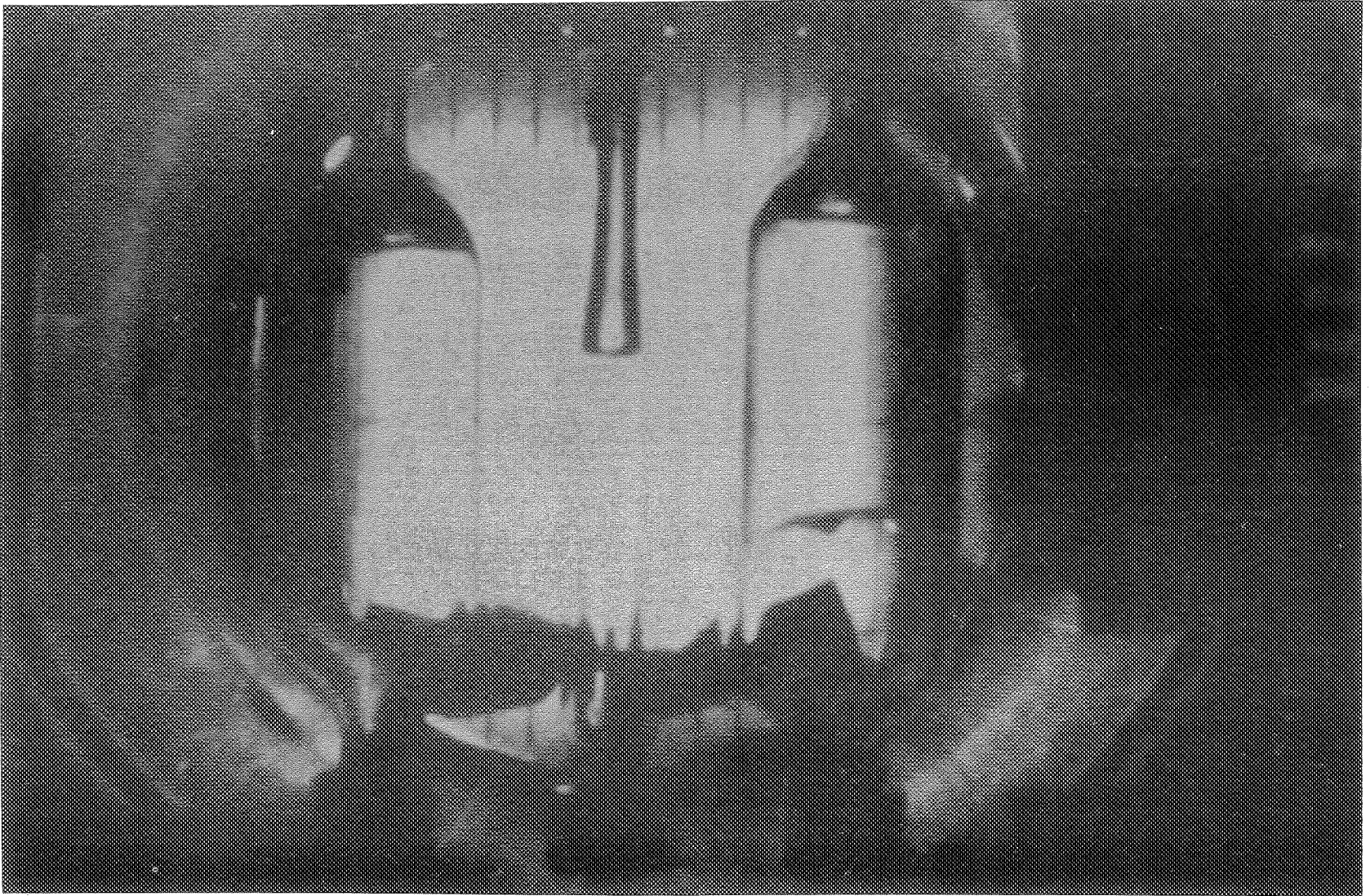
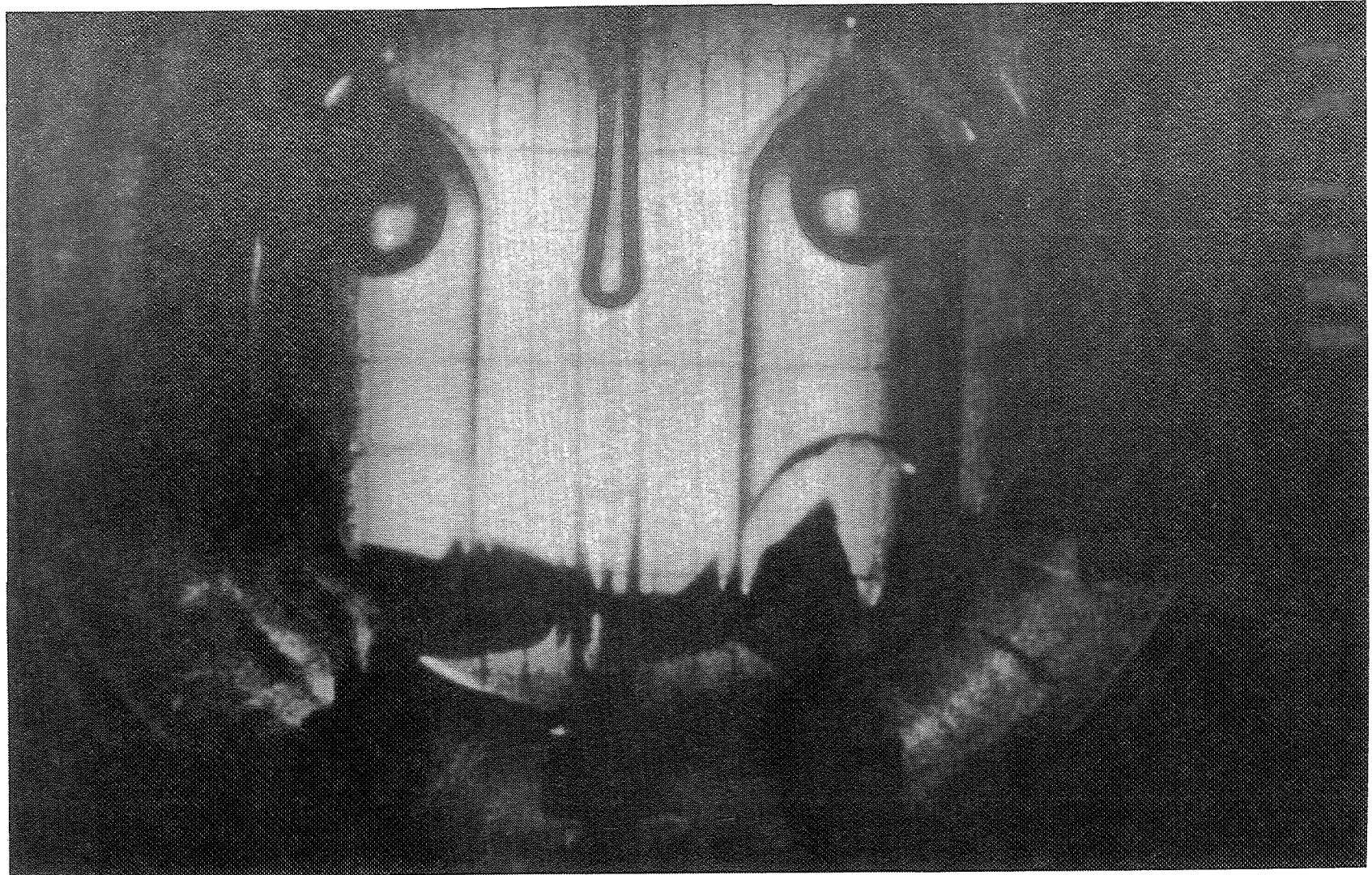


Figure 6.



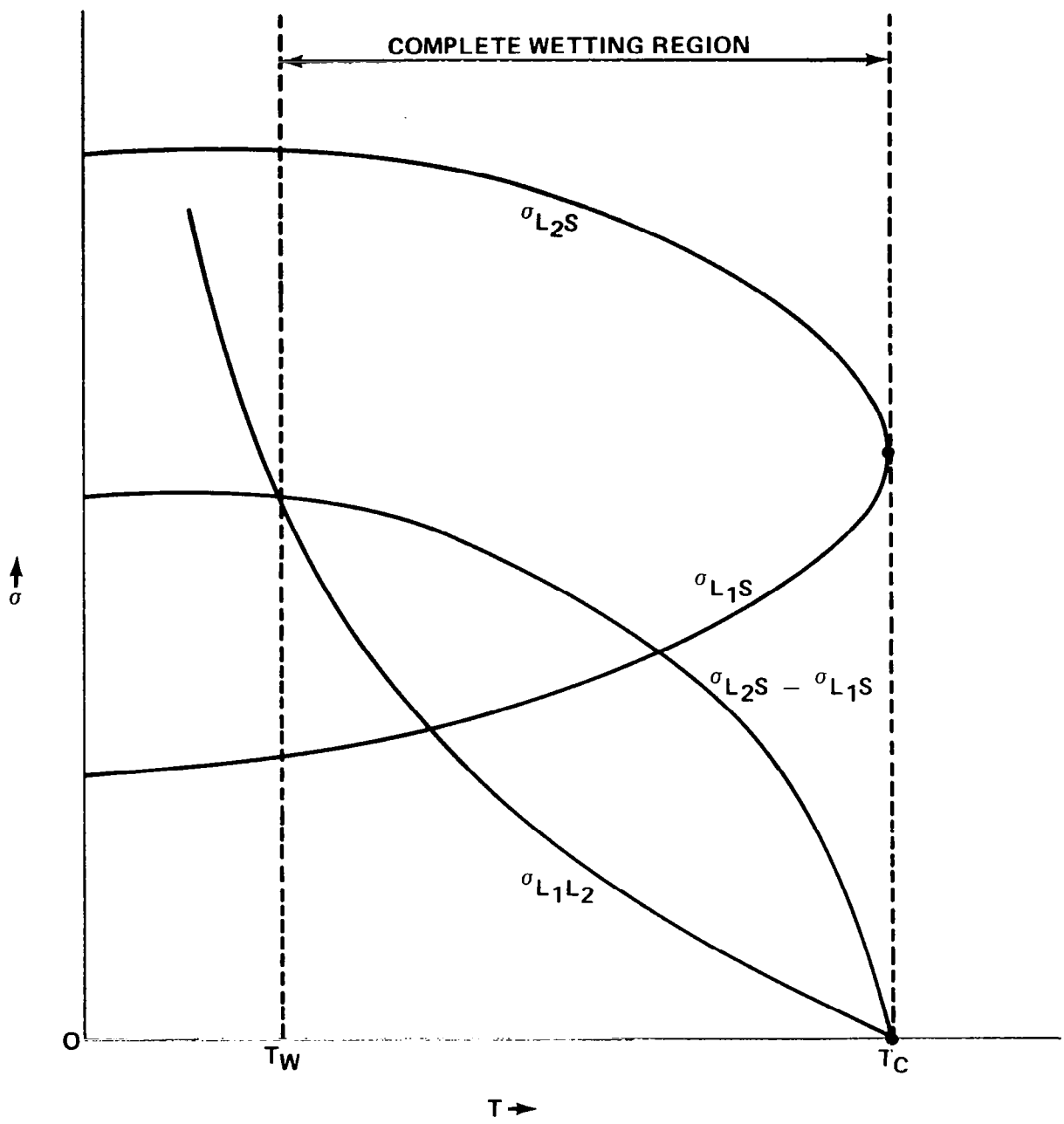
ONE 'G'

Figure 7



LOW 'G'

Figure 8



VARIATION OF INTERFACIAL ENERGIES WITH TEMPERATURE

Figure A.



# SOLIDIFICATION AND CRYSTAL GROWTH OF SOLID SOLUTION SEMICONDUCTING ALLOYS

by

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## ABSTRACT

Problems associated with the solidification and crystal growth of solid-solution semiconducting alloy crystals in a terrestrial environment are described. In particular, a detailed description is given of the results for the growth of mercury cadmium telluride (HgCdTe) alloy crystals by directional solidification, because of their considerable technological importance.

A series of HgCdTe alloy crystals has been grown from pseudobinary melts by a vertical Bridgman method [1-3] using a wide range of growth rates and thermal conditions. Precision measurements were performed to establish compositional profiles for the crystals. The compositional variations are related to compositional variations in the melts that can result from two-dimensional diffusion or density-gradient driven flow effects ahead of the growth interface. These effects are discussed in terms of the alloy phase equilibrium properties [1,2,4-6], the recent high temperature thermophysical data for the alloys [7,8], and the highly unusual heat-transfer characteristics of the alloy/ampule/furnace system [2,3-9] that may readily lead to double-diffusive convective flows in a gravitational environment.

1. S. L. Lehoczky, F. R. Szofran and B. G. Martin, *Advanced Methods for Preparation and Characterization of Infrared Detector Materials, Part I*, NASA CR-161598, 1980.
2. S. L. Lehoczky and F. R. Szofran, *Advanced Methods for Preparation and Characterization of Infrared Detector Materials, Part II*, NASA CR-161949, 1981.
3. S. L. Lehoczky and F. R. Szofran, in: *Materials Processing in the Reduced Gravity Environment of Space*, Vol. g, Ed. G. E. Rindone (North-Holland, Amsterdam 1982), p. 409.
4. F. R. Szofran and S. L. Lehoczky, *J. Electron, Mater.* 6, 1131 (1981).
5. F. R. Szofran and S. L. Lehoczky, *J. Electron, Mater.* 12, 713 (1983).
6. J. D. Kelley, B. G. Martin, F. R. Szofran and S. L. Lehoczky, *J. Electrochem. Soc.* 129, 2360 (1982).
7. D. Chandra and L. R. Holland, *J. Vac. Sci. Technol. A1*, 1620 (1983).
8. L. R. Holland and R. E. Taylor, *J. Vac. Sci. Technol. A1*, 1615 (1983).
9. R. J. Naumann and S. L. Lehoczky, *J. Cryst. Growth* 61, 707 (1983).

# INORGANIC COMPOSITES FOR SPACE APPLICATIONS

by

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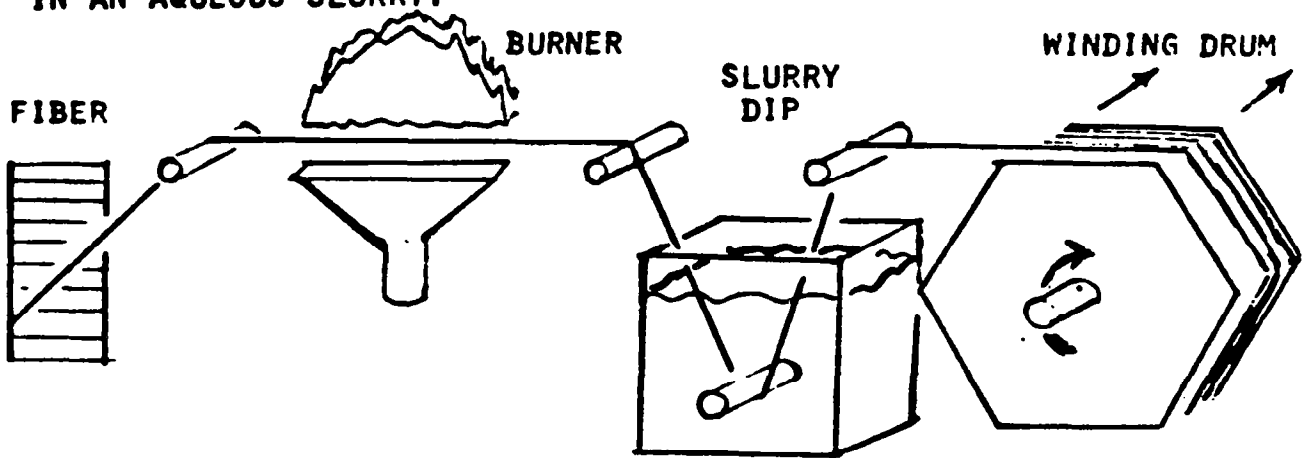
## ABSTRACT

Corning Glass Works has conducted internal studies and has had cooperative programs with other organizations for the development of inorganic composite materials. Some of these composites are well suited for space applications. An overview of the results of the work are presented herein.

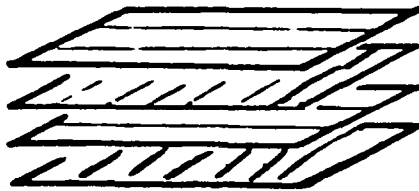
The composites do not contain any organic materials, and therefore, are not subject to degradation by ultraviolet radiation, volatilization of constituents, or embrittlement at low temperatures. The corning composites consist of glass, glass-ceramics or ceramic matrices, reinforced by refractory whiskers or fibers. Such composites have the low thermal expansion, refractoriness, chemical stability and other desirable properties usually associated with the matrix materials. However, the composites also have a degree of toughness which is extraordinary for refractory inorganic materials.

## COMPOSITE PROCESS

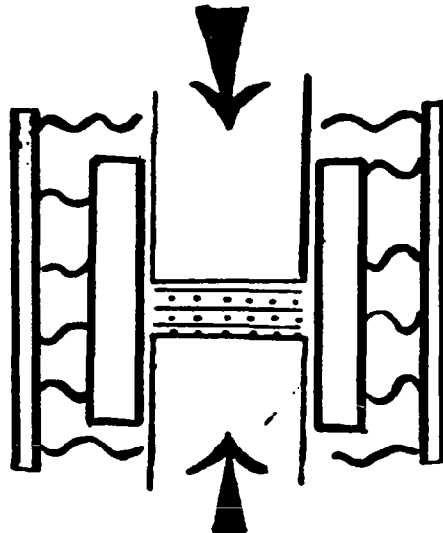
- A. **PREPREG - INFILTRATE FIBER YARNS WITH POWDERED GLASS SUSPENDED IN AN AQUEOUS SLURRY.**



- B. **LAY-UP - CUT PREPREG TO DESIRED SHAPE AND STACK IN BEST ORIENTATION FOR USE.**



- C. **HOT PRESS - CONSOLIDATE IN GRAPHITE MOLD USING ENOUGH PRESSURE TO ACHIEVE MECHANICAL COMPACTION AND ASSIST SINTERING.**



## FIBER/WHISKER REINFORCED COMPOSITES

VS.

## MONOLITHIC CERAMICS

### ADVANTAGES

- . HIGHER FRACTURE TOUGHNESS AND RELIABILITY
- . HIGHER DESIGN STRENGTHS AND OPERATING TEMPERATURES (EFFICIENCY)
- . HIGHER DIMENSIONAL STABILITY
- . LOWER FABRICATION TEMPERATURES

### UNIQUENESS OF GLASS-CERAMIC APPROACH

#### COMBINATION OF

- LOW-FABRICATION TEMPERATURE ( $T \leq 1400^{\circ}\text{C}$ )
  - MINIMIZE THE FIBER DEGRADATION
- REFRACTORINESS
  - TYPICALLY 200-400°C INCREASE IN USE TEMPERATURE

ORIGIN OF FRACTURE TOUGHNESS

- INTERFACIAL REACTION OF C/SiC WITH SILICATES
  - FIBER STRENGTH
  - BOND STRENGTH

BOND STRENGTHFRACTURE MECHANISMSTRENGTH AND TOUGHNESS

"TOO WEAK"

NO REINFORCEMENT

BRITTLE AND WEAK

"TOO STRONG"

CRACKS RUN ACROSS  
THE INTERFACE

BRITTLE AND WEAK

"INTERMEDIATE"

INTERFACIAL DEBONDING  
CRACK DEFLECTIONS  
FIBER PULL-OUTS

TOUGH (FIBROUS) AND STRONG

TYPICAL SiC FRC\* VS. SiC MONOLITHIC CERAMIC

<u>MATRIX</u>	<u>LAS III</u>	<u>BMAS II</u>	<u>EXP. (1)</u>	<u>MONOLITHIC <math>\alpha</math>-SiC (CARBORUNDUM)</u>
DENSITY (g/cc)	2.5	2.7	2.7	3.1
YOUNG'S MOD. (MSI)	17	20	20	59
MOR (KSI) 25°C	135	150	140	65
FRACTURE TOUGH- NESS $K_{1C}$ (KSI $\sqrt{IN}$ )	15-25	10-15	10-15	4
FRACTURE ENERGY (KJ/M <sup>2</sup> )	3-4.5	--	--	0.025
THERMAL EXPAN- SION (10 <sup>-6</sup> /°C, 25- 900°C)	2.2	3.5	4.0	4.5
MAX. USE TEMP. (°C)	1150	1250	1350	1450

\*30-35 v/o FIBER, UNIAXIAL REINFORCEMENT

## APPLICATIONS

- HIGH TEMPERATURE TO 1300°C
  - JET ENGINE COMPONENTS (VANES, BLADES, AFTER-BURNER FLAP)
  
  - ADVANCED GAS TURBINE
    - POWER TURBINE, GASIFIER AND POWER TURBINE BACKPLATES
  
  - ADIABATIC DIESEL ENGINE
    - CYLINDER TOP AND LINING
  
- LOW TEMPERATURE TO -200°C (CARBON/GLASS)
  - SPACE STRUCTURE FOR LASER AND COMMUNICATION MIRRORS
    - DIMENSIONAL STABILITY, THERMAL SHOCK RESISTANCE,  
NO UV RADIATION DAMAGE, NO MOISTURE ABSORPTION,  
ZERO EXPANSION

# SYNTHETIC MICA MATERIALS

---

## CORNING GLASS WORKS

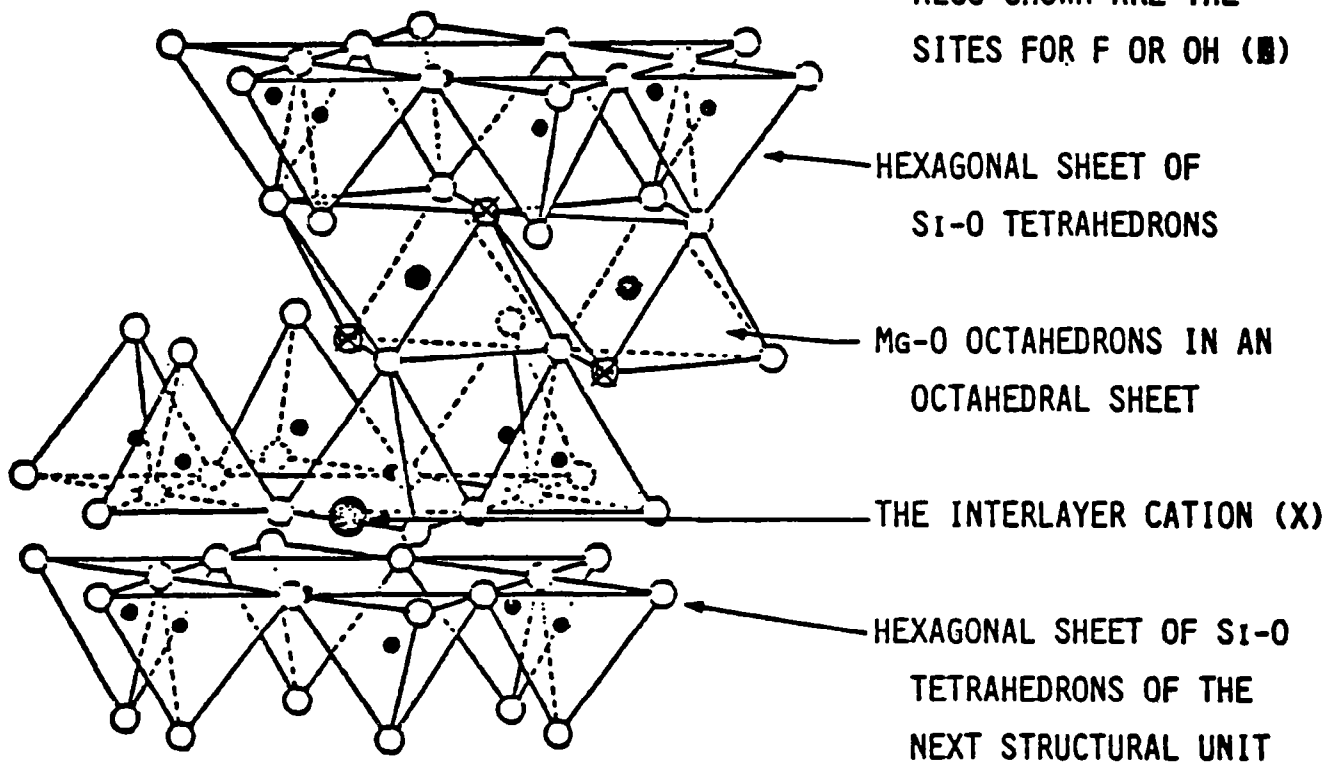
CORNING SYNTHETIC MICA MATERIALS ARE A FAMILY OF PRODUCTS FORMED FROM FLUOROMICA GLASS-CERAMICS BY A PATENTED PROCESS. THE GLASS-CERAMIC IS REACTED WITH WATER (OR OTHER POLAR LIQUIDS), YIELDING VERY SMALL PLATELETS OF EXCEPTIONALLY HIGH ASPECT RATIO. THIS UNUSUAL MORPHOLOGY AND CERTAIN ION-EXCHANGE PROCESSES PRODUCE MATERIALS WITH THE UNIQUE PROPERTIES DESCRIBED IN THE FOLLOWING PAGES.

SYNTHETIC MICA PRODUCTS ARE PRESENTLY AVAILABLE FROM CORNING'S LABORATORIES, WHERE THEY ARE PRODUCED IN LIMITED QUANTITIES. PRODUCTION FACILITIES ARE BEING PLANNED IN ACCORDANCE WITH MARKET REQUIREMENTS.

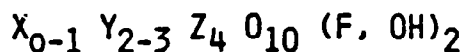


**MICA STRUCTURE**

CONSISTS OF OCTAHEDRAL SHEET SANDWICHED BETWEEN TWO TETRAHEDRAL SHEETS ALSO SHOWN ARE THE SITES FOR F OR OH (●)



**GENERALIZED STRUCTURAL FORMULA**



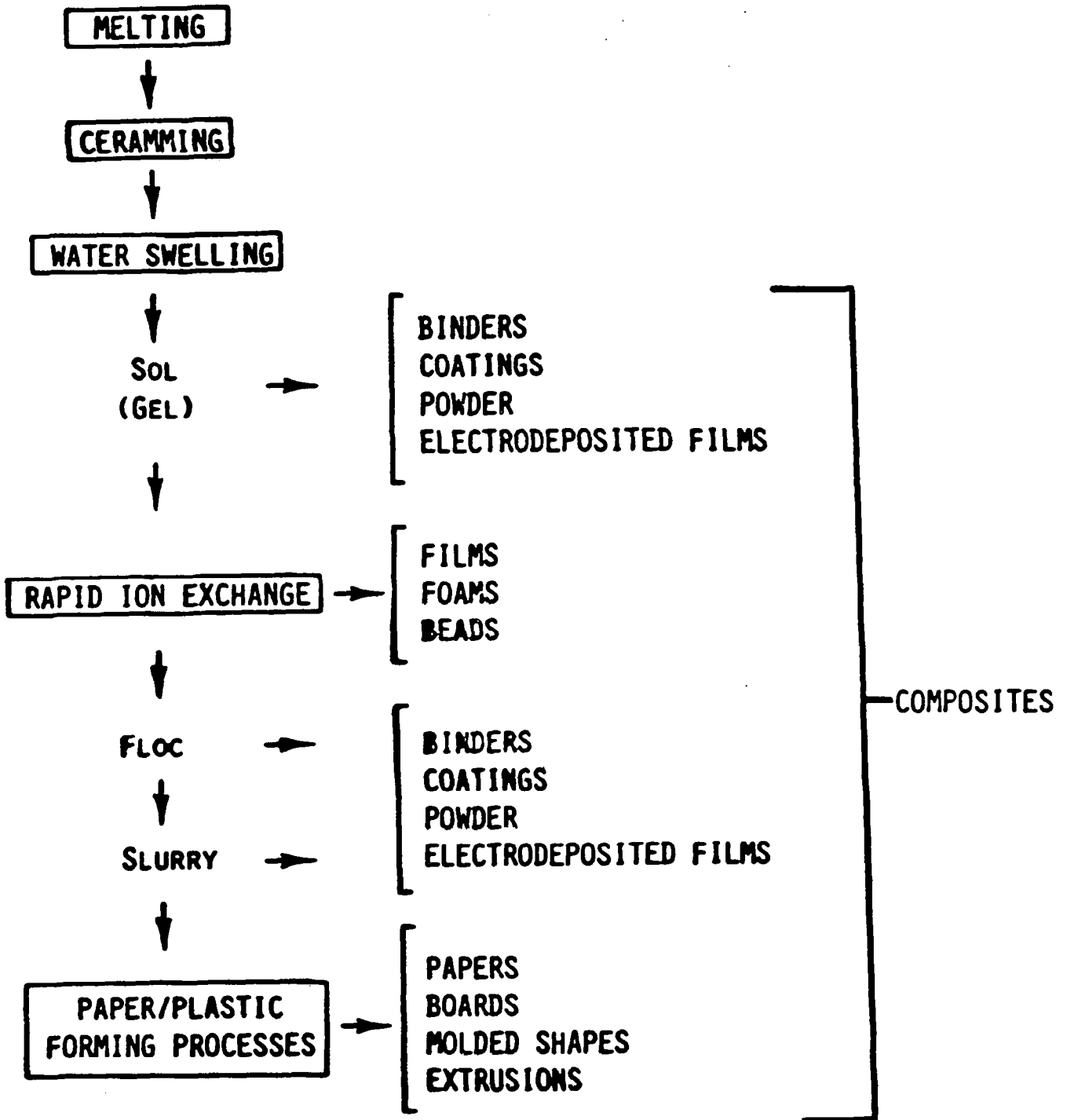
**CATIONS TYPICALLY:**

INTERLAYER: X = Li, Na, K, Ca, Sr, Ba, Pb, NH<sub>4</sub>, Rb, Cs

OCTAHEDRAL: Y = Mg, Al, Li, Mn, Fe, Zn, Cu, Ni, Co

TETRAHEDRAL: Z = Si, Al, B, P, Ge, Be

# BASIC PROCESS & PRODUCTS



## PARTICULATE FORMS OF CORNING'S SYNTHETIC MICA MATERIALS

GEL (SOL) - A COLLOIDAL SUSPENSION OF SYNTHETIC MICA PLATELETS IN A POLAR LIQUID.

FLOC - FINE AGGLOMERATES OF SYNTHETIC MICA PLATELETS, MADE BY EXTRUDING GEL THROUGH PIN-HOLE ORIFICES INTO AN ION EXCHANGE SOLUTION.

SLURRY - USUALLY AN AQUEOUS DISPERSION OF ION-EXCHANGED SYNTHETIC MICA PLATELETS. NON-AQUEOUS SUSPENSIONS CAN ALSO BE FORMED.

SPRAY DRIED PARTICULATES - GEL, FLOC, OR SLURRY SPRAY DRIED. ADDITIVES SUCH AS COUPLING AGENTS CAN BE INCORPORATED.

## MONOLITHIC FORMS OF CORNING'S SYNTHETIC MICA MATERIALS

FILM - CONTINUOUS THIN FILMS FORMED BY EXTRUDING GEL THROUGH A SLOT ORIFICE INTO AN ION EXCHANGE SOLUTION.

PAPER - CONTINUOUS SHEET FORMED BY DEPOSITING SLURRY (ION EXCHANGED GEL) ON CONVENTIONAL PAPER MAKING EQUIPMENT.

BOARD - THICK SHEET PRODUCED FROM FLOC OR SLURRY BY DEPOSITION, MOLDING, PRESSING, EXTRUSION OR LIKE PROCESSES.

FOAM - LIGHTWEIGHT MATERIALS PRODUCED BY SIMULTANEOUS ION-EXCHANGE AND FROTHING.

BEADS - HOLLOW, SOLID OR POROUS; FORMED BY VARIATIONS OF THE EXTRUSION AND FOAM PROCESSES.

## **CORNING GLASS WORKS**

### **SYNTHETIC MICA MATERIALS**

#### **UNIQUE CHARACTERISTICS**

- . HIGH USE TEMPERATURE**
- . GOOD DIELECTRIC PROPERTIES**
- . RESISTS STRONG ALKALIES AND ACIDS**
- . CAN FORM COMPOSITES WITH ORGANIC AND/OR OTHER INORGANIC MATERIALS**
- . VARIETY OF PARTICULATE AND MONOLITHIC FORMS**
- . NON-TOXIC**

## **FLUIDS EXPERIMENT APPARATUS (FEA)**

by

**Mike Martin**  
Space Transportation and Systems Group  
Rockwell International  
Huntsville, Alabama 35801

### **ABSTRACT**

The FEA is a modular zero gravity chemistry/physics laboratory to support fundamental space processing research. It can be used to conduct basic and applied process or product experiments in general liquid chemistry, crystal growth, fluid mechanics, thermodynamics, and cell culturing. The various FEA subsystems can be readily configured to perform this wide range of investigations. Designed to be operated by a crew member in the orbiter middeck, the FEA can be accommodated on most Space Shuttle missions.



# FEA CONCEPT

FUNDAMENTAL SPACE PROCESSING RESEARCH

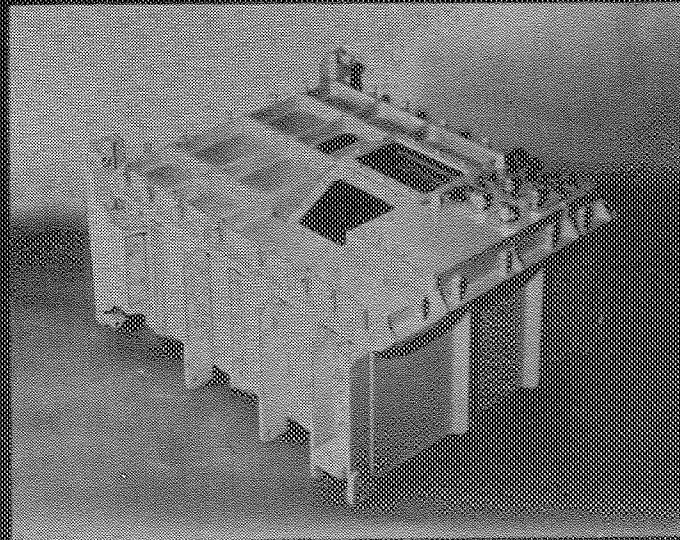
MODULAR ZERO GRAVITY CHEMISTRY/PHYSICS LABORATORY

## PURPOSES

- BASIC PROCESS/PRODUCT RESEARCH
- GENERAL LIQUID CHEMISTRY
- CRYSTAL GROWTH
- FLUID MECHANICS
- THERMODYNAMICS
- CELL CULTURING

## OPERATIONAL CHARACTERISTICS

- HEAT/COOL SAMPLES
- MIX GASSES, LIQUIDS, & SOLIDS
- STIR SAMPLES
- CONTAINED SAMPLES
- FLOAT ZONE SAMPLES
- VACUUM AVAILABLE
- MEASURE TEMPERATURE/VISCOSITY
- PHOTOGRAPH (MOVIE) SAMPLE
- RECORD DATA
- ASTRONAUT OPERATED
- SHUTTLE MID DECK



145571-45122



## FEA FLOAT ZONE CONFIGURATION

HEATER TRANSPORT  
 BIDIRECTIONAL  
 0.5 - 10 IN./HR  
 0.5 IN./MIN SLEW

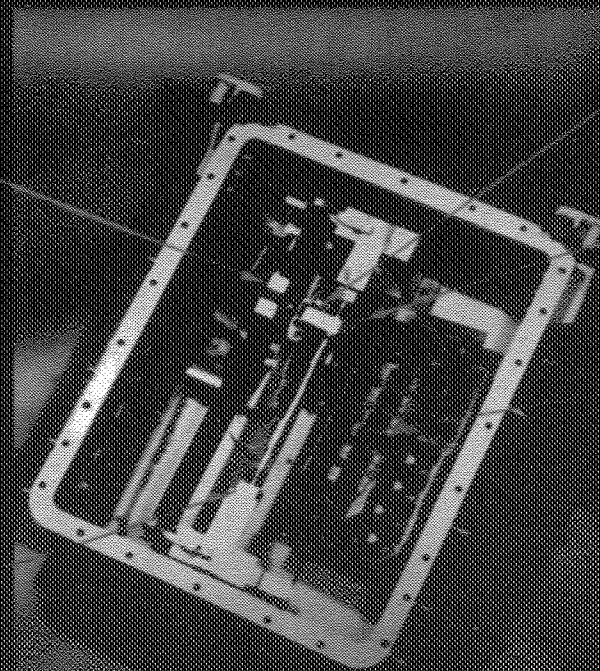
HEATER  
 100W

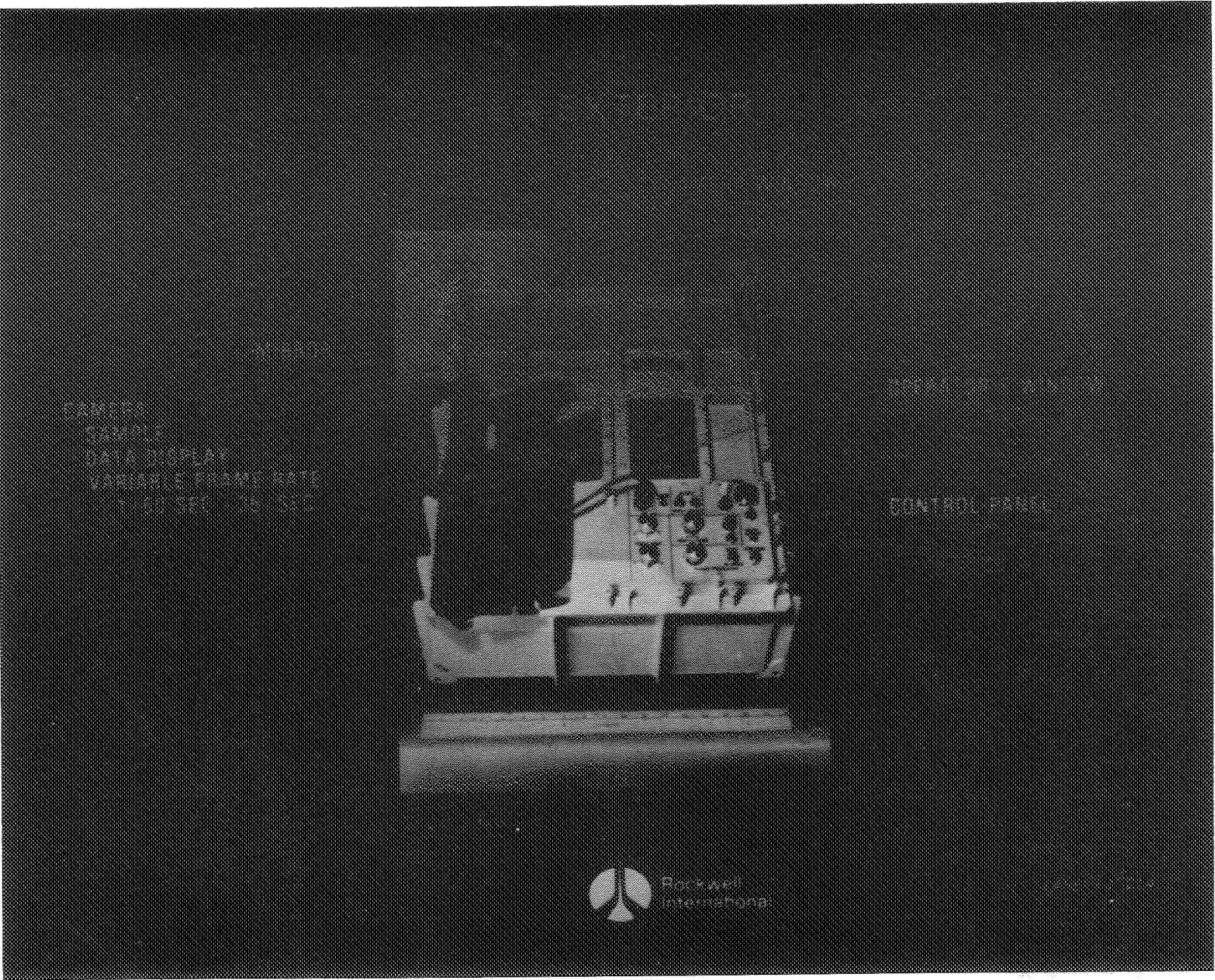
GAS RESERVOIR  
 ARGON — 2 PSI

DATA DISPLAY MODULE  
 TIME SEC  
 HEATER POWER W  
 HEATER POSITION IN  
 HEATER RATE IN/HR  
 TEMPERATURES IN

SAMPLE CONTAINER  
 8.5 IN LONG  
 0.65 IN DIA

SAMPLE  
 0.4 IN DIA





CAMERA  
SCALE  
DATA DISPLAY  
VARIATION FRAME RATE  
100 200 300 400

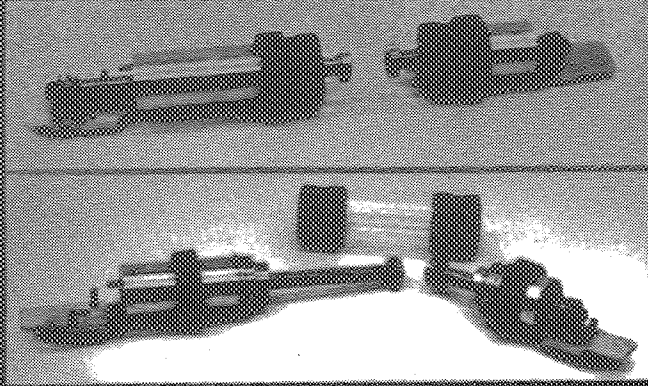
OPERATIONAL MODE

CONTROL PANEL

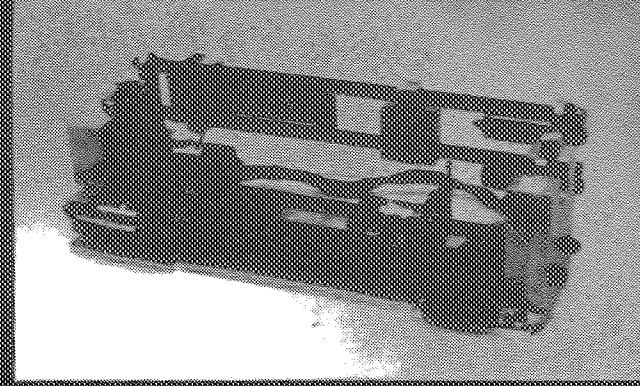
 Rockwell  
International

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## FEA OPTIONAL SUBSYSTEMS



FLUIDS MANIPULATION  
EXPERIMENT CONTAINER



EXPERIMENT MANIPULATION  
ASSEMBLY

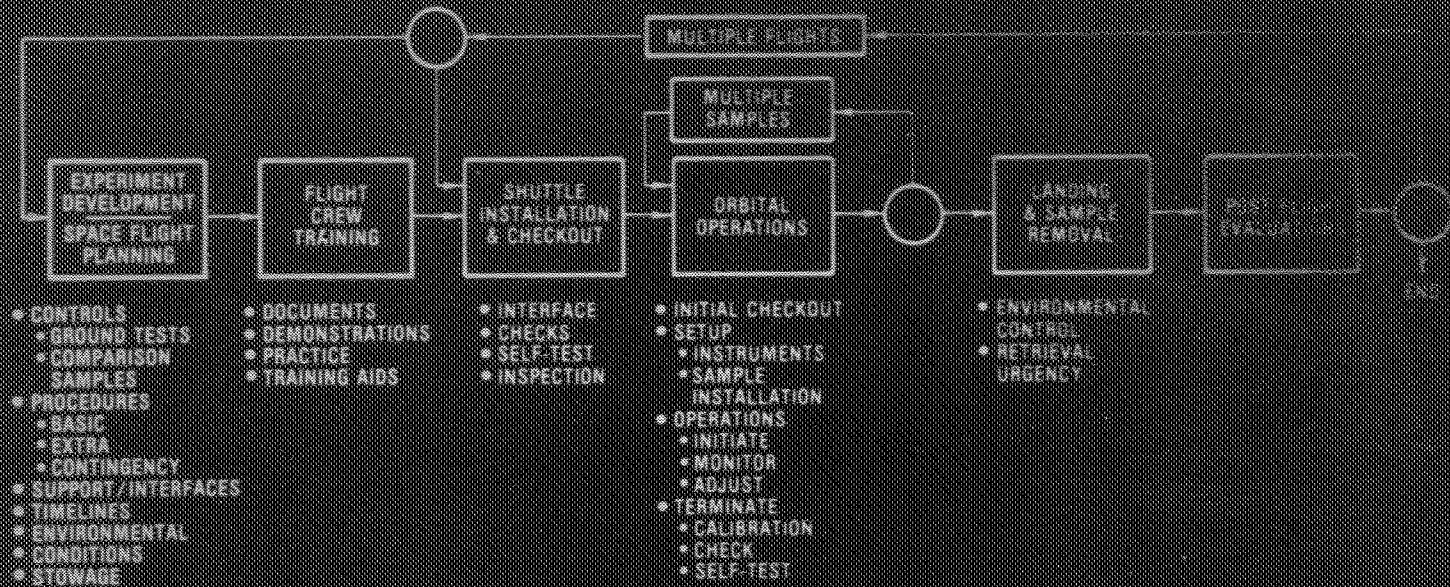


FLUIDS STORAGE &  
PUMPING ASSEMBLY

### OTHERS

- BULK FLUID CHEMISTRY CHAMBER
- LIVING CELL INCUBATOR
- MULTISAMPLE COLUMN
- CUSTOM HEATER DESIGNS
- SAMPLE CHILL BLOCKS
- SPECIAL INSTRUMENTATION

# TYPICAL EXPERIMENT PROJECT FLOW

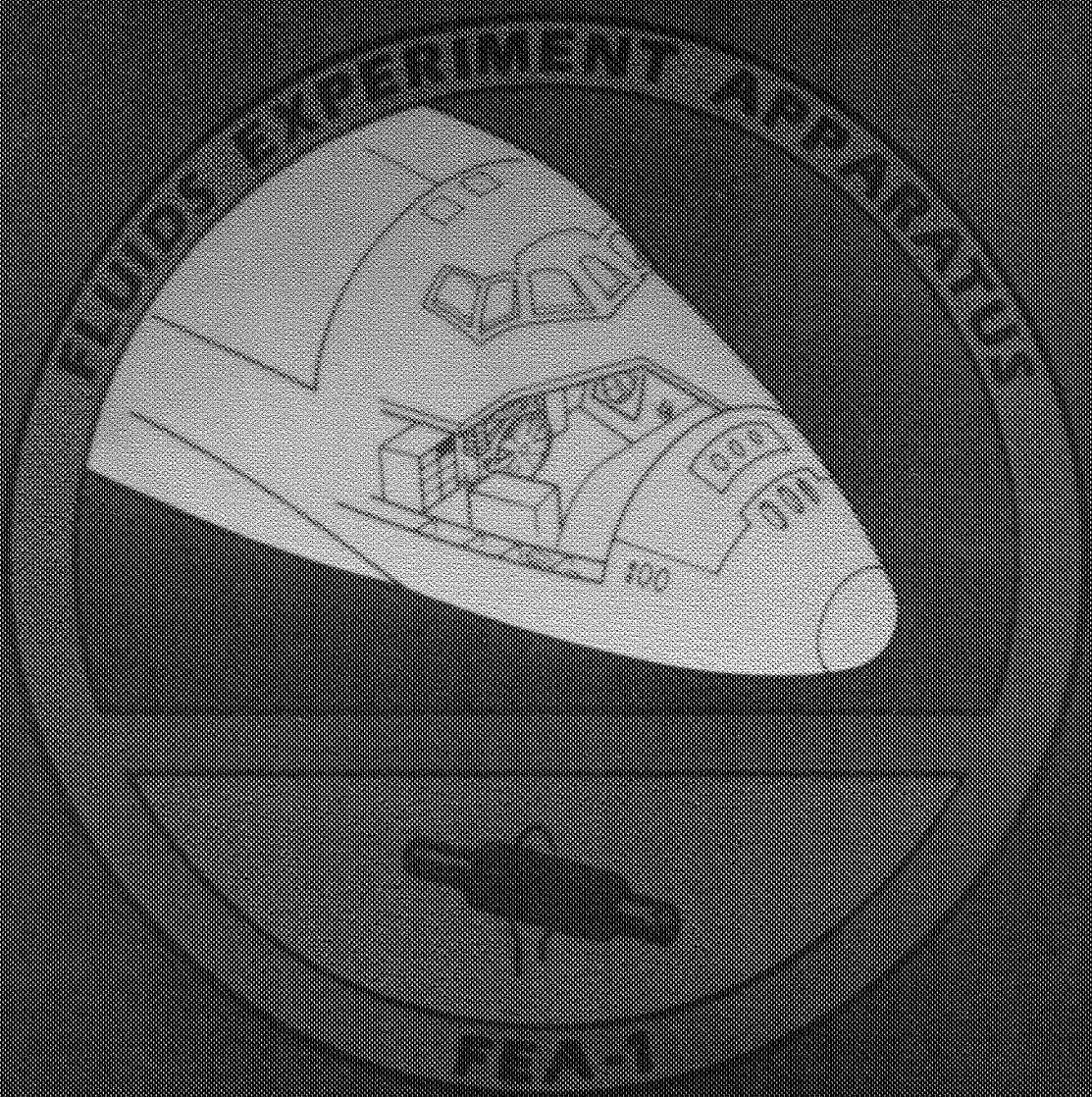


## GUIDELINES

- USE CREW CAPABILITIES
- ALLOW TIMELINE FLEXIBILITIES
- MINIMIZE SPECIFIC SHUTTLE REQUIREMENTS



Rockwell International



## FEA-1 MISSION

"THE PURIFICATION AND GROWTH OF SINGLE CRYSTAL INDIUM  
BY THE FLOAT ZONE TECHNIQUE IN A ZERO GRAVITY ENVIRONMENT"

### OBJECTIVES

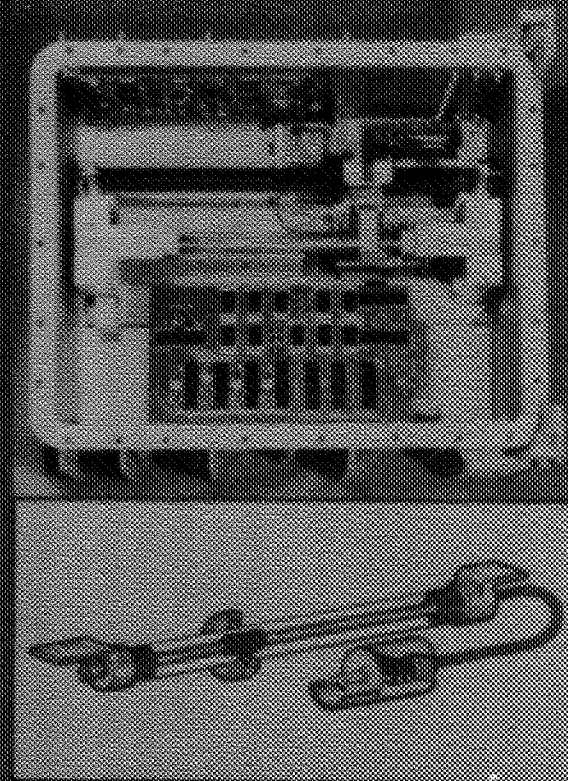
- FLIGHT TEST THE FEA
- DEMONSTRATE THE PROCESSING TECHNIQUE
- STUDY THE MATERIAL PROPERTIES
- INVESTIGATE PROCESS BENEFITS & LIMITATIONS

### ANTICIPATED RESULTS

- IMPROVED CRYSTAL QUALITY & DOPING UNIFORMITY
- PROCESS LESS DEPENDENT ON MATERIAL PROPERTIES
- KNOWLEDGE ABOUT
  - FLOAT ZONE LENGTH EFFECTS
  - SURFACE TENSION (MARANGONI) EFFECTS
  - MICRODYNAMIC/THERMAL ENVIRONMENT SENSITIVITY
  - THERMAL GRADIENT/GROWTH RATE (G/R) EFFECTS
  - MANUAL EXPERIMENT CONTROL SUSTAINABILITY

### IMPROVED SEMICONDUCTORS -- SIMPLER SYSTEMS

- VERY LARGE HIGH YIELD INTEGRATED CIRCUITS
- HIGH PERFORMANCE DETECTORS
- ADVANCED MICROWAVE DEVICES



1987-1988

# COMMERCIALIZING THE TRANSFER ORBIT STAGE

by

Michael W. Miller  
Orbital Sciences Corporation  
Vienna, Virginia 22180

## ABSTRACT

Orbital Sciences Corporation (OSC), a technically-based management, marketing, and financial corporation, was formed in 1982 to provide economical space transportation hardware and services to commercial and government users. As its first project, OSC is developing a new medium-capacity upper stage for use on NASA's Space Shuttle, called the TOS. Before the TOS project successfully entered the development stage, many obstacles for a new company operating in the established space industry had to be overcome. This paper describes key milestones necessary to establish this new commercial space endeavor.

Historical milestones began with the selection of the project concept and synthesis of the company. This was followed by venture capital support which led to early discussions with NASA and the selection of a major aerospace company as prime contractor. A landmark agreement with NASA sanctioned the commercial TOS concept and provided the critical support necessary to raise the next round of venture capital. Future challenges including project management and customer commitments are also discussed.

## BACKGROUND

Orbital Sciences Corporation (OSC), a technically-based management, marketing, and financial corporation, was formed in 1982 to provide economical space transportation hardware and services to commercial and government users. As its first project, OSC is developing a new medium-capacity upper stage for use on NASA's Space Shuttle, called the Transfer Orbit Stage (TOS).

The TOS project represents an evolutionary milestone in the nation's attempts to commercialize space. Responding to the Reagan administration's mandate and to Congressional guidelines, NASA is encouraging private-sector initiatives in space activities. OSC's TOS program is foremost among a variety of commercial ventures being encouraged by the space agency. This paper will explore key features of the TOS program and this commercialization effort.

## PRELIMINARY MARKET STUDIES AND PROJECT SYNTHESIS

Since the introduction of NASA's Space Shuttle in 1981, the supply of launch services has shifted increasingly to a reliance on this reusable launch vehicle. The shift in payloads from ELVs to Shuttle has necessitated a need for a group of STS upper stages to boost payloads from the Shuttle low-Earth park orbit to their final geostationary locations. These upper stages can be aggregated into three categories according to their weight delivery capacity as follows:

- low capacity (1000 to 3000 lb capacity to geostationary orbit)
- medium capacity (3000 to 7000 lb capacity to geostationary orbit)
- high capacity (7000 to 12000 lb capacity to geostationary orbit)

At present, several low-capacity perigee stages, which perform the first of two required maneuvers to place satellites in geosynchronous orbit, are available in the capacity band from 1200 to 2200 lb of delivered payload. These upper stages, called Payload Assist Modules (PAM's), were developed commercially by McDonnell Douglas Corporation in a cooperative arrangement with NASA and are operationally compatible with the Delta ELV. McDonnell Douglas has flown over 15 PAM's to date and approximately 50 more are on the Shuttle manifest through the 1980's.

In the medium-capacity range, the Air Force's Inertial Upper Stage (IUS), which became operational on the STS in 1983, can deliver up to 5000 lb to geostationary orbit, in this case by providing both perigee and apogee boosts to the payload. Because of an array of special military requirements and concomitant high cost, the IUS is not generally an attractive launch option for commercial and NASA missions. No other upper stages now serve the medium-capacity segment, the segment which will show the fastest growth in commercial and government demand during 1985-1995.

At the upper end of the spectrum a large-capacity stage will be available in 1986 when the NASA/Air Force STS/Centaur is expected to be ready for a number of very high energy planetary and military missions. The Centaur is a liquid propellant stage that burns hydrogen and oxygen. It is a fairly complicated vehicle to build and operate requiring extensive safety modifications to the Shuttle Orbiter.

While the development of the Space Shuttle was proceeding in the U.S., the launch services market was being penetrated for the first time with serious competition from Europe. Ariespace's Ariane series, from Ariane 1 (2100 lb capacity to geo. orbit) which became operational in 1982, to Ariane 4 (5200 lb capacity to geo. orbit) which is planned for 1987, represents a serious threat to the U.S. dominance of the space transportation market. Aggressive marketing tactics, buttressed by government subsidies, have allowed Ariespace to attract several U.S. domestic communication satellite customers, even amid development delays and flight failures with Ariane 1.

OSC's evaluation of available upper stage systems and trends in satellite design led to the program to develop the TOS (see Figure 1). NASA, through feasibility and preliminary design studies conducted at Marshall Space Flight Center, identified the need for a low-cost, medium-capacity upper stage for use on the Shuttle. OSC's own market studies also led to the conclusion there was a substantial upper stage market for U.S. commercial, NASA, DOD, and international payloads in the same capability range.

Believing that a new business climate was developing for the propagation of commercial ventures in space in general, and space transportation services in specific, OSC in 1982 proposed to NASA that it finance, develop, and market the TOS as a commercial program similar to the PAM-D venture.



<b>SYSTEM</b>	<b>CAPACITY (lb)</b>	<b>COST (K\$/lb)</b>	<b>ILC*</b>
Shuttle/PAM-D	1,200	18.0	1982
Delta 3920/PAM-D	1,600	18.5	1981
Arian I	2,100	17.0	1982
Shuttle/PAM-A	2,200	18.0	1983
Atlas G/Centaur	2,700	24.0	1984
Ariane 3	3,100	16.0	1985
Titan 34D/IUS	4,100	34.0	1982
Shuttle/IUS	5,000	25.0	1983
Ariane 4	5,200	15.0	1987
Shuttle/TOS	6,800	12.0	1986
Shuttle/Centaur	12,000	14.0	1986

\*Initial launch capability (year).

Figure 1. Competitive Stage Assessment

## NASA AGREEMENT AND PROJECT TEAM

NASA entered into a Memorandum of Understanding with OSC in December 1982 for commercialization of the TOS. During the early part of 1983, OSC provided NASA with detailed information on its abilities and prospects for financing and managing the project. Extensive negotiations during early 1983 culminated in a landmark final agreement between NASA and OSC in April 1983, which transferred responsibility for the TOS program from the space agency to OSC.

In return for NASA's agreement to discontinue any Government-financed programs to develop a TOS-class stage, OSC promised to finance, develop, and become the exclusive marketing agent for the vehicle.

Among other features of this unique accord is NASA's commitment to establish a TOS project office at Marshall Space Flight Center (which is now operational). This office will participate as a technical monitor and adviser to OSC during TOS development and operation phases (1983-1994); will assist in STS safety, interface, and related activities; and will ultimately place NASA's "seal of approval" on the TOS system. This gives OSC's customers positive assurance of a dependable, cost effective stage for Shuttle applications.

During the second half of 1982, OSC held meetings with and reviewed technical and business proposals of seven aerospace companies interested in serving as the prime contractor and systems integrator for TOS. From this group, OSC selected Martin Marietta to develop, manufacture, test, and integrate the TOS because of its superior technical approach to TOS development (as corroborated by independent NASA assessments), innovative attitude toward cost savings, existing capability in Shuttle payload integration, and experience in space launch systems spanning a 25-year period. OSC and Martin Marietta signed a preliminary agreement to this effect in January 1983, and a final contract for vehicle design studies and full-scale development work in May 1983.

As prime contractor to OSC, Martin Marietta's Denver Aerospace Division will develop and produce the TOS and provide OSC's customers with payload integration and related launch services. As NASA's second largest contractor, Martin Marietta currently manufactures the external tank for the space shuttle and has a long history of working with NASA on important elements of the nation's space programs. Martin Marietta also serves as systems integrator to

the Air Force for defense payloads on the Space Shuttle. As manufacturer of the Titan 34D launch vehicle, Martin Marietta is well positioned to provide valuable assistance in arranging for the use of the Titan 34D as a backup for Space Shuttle launches of the TOS.

In addition, United Technologies' Chemical Systems Division has joined the project team as supplier of the solid rocket motor which powers the stage. The work of Martin Marietta and the Chemical Systems Division in these areas will be supervised by an OSC technical and contract management staff. The TOS Project Office, established under the terms of the NASA/OSC agreement at NASA's Marshall Space Flight Center, will ensure compliance with Space Shuttle flight safety requirements (See Figure 2).

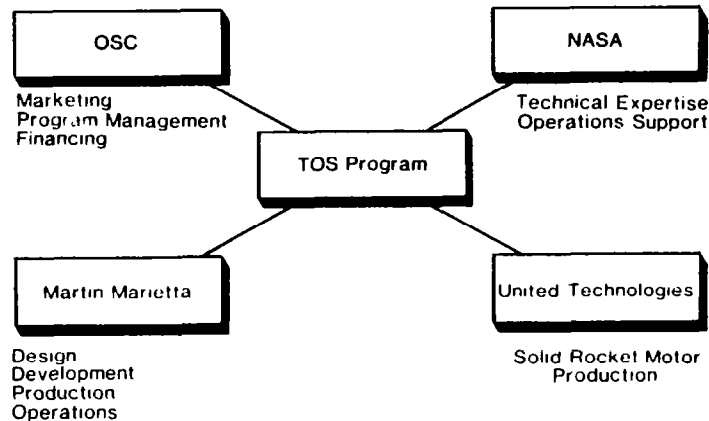


Figure 2. TOS Program Team.

### FINANCIAL CONSIDERATIONS

The funds required to meet TOS project requirements through 1986 are expected to be \$40 million. During 1983, OSC secured firm commitments of equity, debt, and limited partnership financing in excess of projected requirements. Joining OSC as financial partners in this project are four of the largest investment banking, venture capital, and financial services firms in the country. They include Rothschild, Inc. of New York, Brentwood Associates, Norwest Growth Fund, and Shearson/American Express, Inc. These financial partners represent, for the first time, the introduction of new sources of capital into space transportation activities. By meeting the financial requirements of the project before full-scale development, NASA and commercial users are guaranteed the TOS will be available.

### TECHNICAL AND PROGRAM FEATURES

The concepts of a commercial venture are embedded throughout the TOS development program. Basic to these are risk reduction measures to ensure the TOS will meet market needs, yet be available on schedule, and at a competitive price. To this end, the TOS will make maximum use of space-qualified, off-the-shelf hardware. For example, while the main propulsion system is based on the extensively tested and flight-proven SRM-1 rocket motor, most of the avionics, reaction control system, and electrical airborne support equipment are also already space-qualified. (See Figure 3).

New design features are incorporated where the commercial user will benefit. These include a length-efficient stage configuration and light-weight Shuttle cradle system to reduce launch costs. Interface compatibility with Ariane and PAM-DII precludes spacecraft attach fitting redesign. While common commercial requirements are met in a simple, low-cost design, mission-unique requirements are satisfied by add-on kits. Thus, TOS users will pay for only the services they need.

Finally, TOS users will be provided with not only hardware, but full "turn-key" services as well. These include spacecraft and payload integration, ground and flight operations, logistics management, and a full range of insurance and finance options.

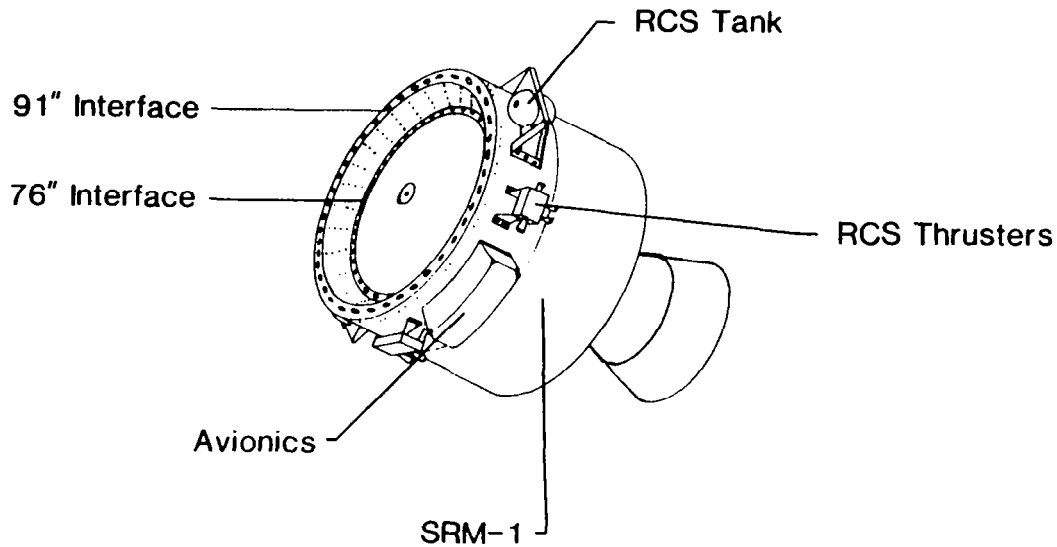


Figure 3. TOS System Configuration.

### PROGRAM STATUS

The TOS program is now moving through full-scale development with an expected initial launch capability of 1986 (See Figure 4). Design definition studies completed during 1983 provided confidence that the TOS will meet or exceed all its performance goals. During 1983, OSC opened their headquarters in a suburb of Washington, DC, and currently employs a 20 person staff in managing the TOS program and marketing the vehicle. The recent Reagan administration policies for the further development of private space endeavors has corroborated OSC's belief that its projects will help develop a new commercial space industry.

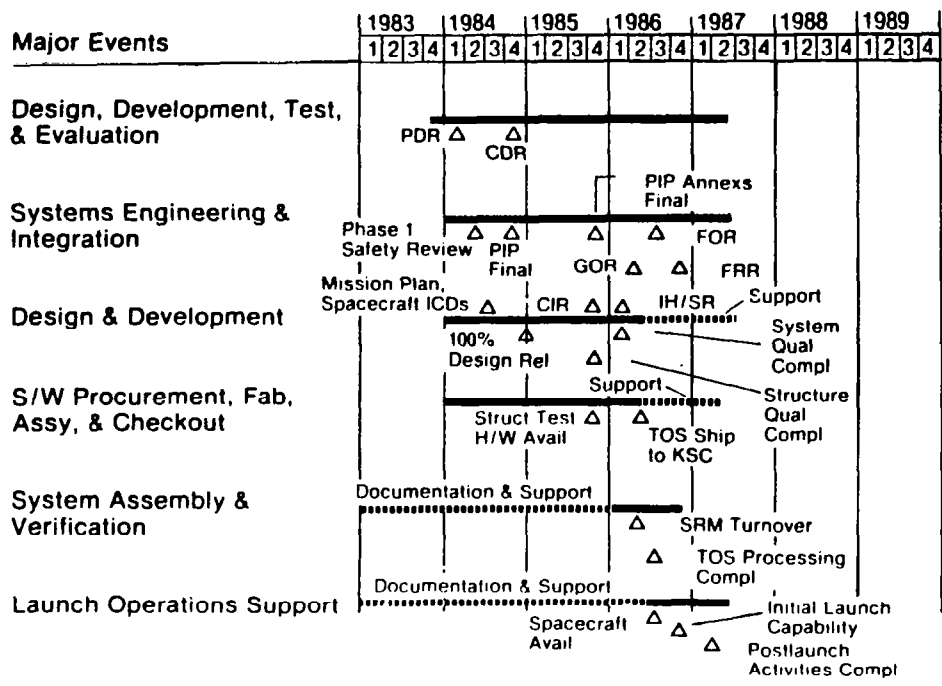


Figure 4. TOS Program Schedule.

## EXTERNAL TANK AFT CARGO CARRIER

by

Thomas B. Mobley  
ACC Project Manager  
Martin Marietta Aerospace  
Denver Aerospace, Michoud Division  
New Orleans, Louisiana 70189

### ABSTRACT

The External Tank (ET) Aft Cargo Carrier (ACC) is a low cost, low risk augmentation of the Space Transportation System (STS). It almost doubles the cargo volume of the STS while minimally impacting other STS elements (orbiter, ET and solid rocket boosters [SRBs]), launch facilities and STS operations.

In addition to increasing the potential volume of cargo carried on a Shuttle launch, the ACC provides the following additional benefits:

- 1) Increased STS competitiveness for payloads;
- 2) Increased cargo manifest flexibility;
- 3) Increased spacecraft design options;
- 4) Alternate manifesting for special payloads; and
- 5) Future space platform/station design options.

This poster paper highlights the ACC and demonstrates its benefits.

# A PROOF-OF-PRINCIPLE GETAWAY SPECIAL FREE-FLYING SATELLITE DEMONSTRATION

by

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Brigham City, Utah 84302

## ABSTRACT

An air traffic control radar calibration satellite will be ejected into a 57 degree, 190 nautical mile orbit from a Getaway Special canister carried by the Space Shuttle in the fall of 1984. During its nine-month orbital lifetime, it will be used by the U.S. Federal Aviation Administration, U.S. military agencies and cooperating governments around the world to measure antenna patterns associated with the existing international air traffic control network.

The satellite will employ three L-band receivers, a UHF command receiver, a VHF telemetry transmitter, associated antennas, a microprocessor, fixed solar arrays, and a power supply to acquire, store and forward signal strength data from some of the 1500 tracking radars operated by member organizations of the International Air Transport Association. Data will be received and processed at a master control station located in Ogden, Utah. The resulting antenna patterns will be supplied to participating agencies at no charge. A second satellite is planned for launch in 1986 into a high-altitude polar orbit with a lifetime of several years in order to provide a long-lived calibration service to the entire international air traffic control system.

The initial satellite and associated ground station are being designed and built by a volunteer consortium of three educational institutions and more than a dozen aerospace companies. Following this initial demonstration of a free-flying Getaway Special satellite, a substantial number of organizations are contemplating commercial uses of the concept. Discussions are being held with NASA concerning the establishment of an appropriate fee for this new class of service.

# SPACE COMMERCIALIZATION: ANALYSIS OF R&D INVESTMENTS WITH LONG TIME HORIZONS

by

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SRI International  
Arlington, Virginia 22209

## ABSTRACT

This paper presents an analysis of a typical hypothetical investment in an R&D project that leads first to a series of orbiting experiments launched by the NASA Shuttle, and later to a commercial production process carried out in space. The eventual profitability is quite large, recovering the total outlay in the first two years of commercial operation, with comparable profits continuing many more years into the future. However, there is an 8-year delay between inception of the R&D and realization of a profit stream. As a result, the Internal Rate of Return is only in the 30% range, which reduces this R&D program to being merely competitive with other corporate investment opportunities. When the risk of failure (inherent in any R&D project) is factored in, the space commercialization project becomes considerably less attractive. This paper analyzes the effects of alternate means of financing such a project, and comments on the differences in risk perceived by diverse investors. In order to investigate the viewpoint of an R&D Limited Partnership, the use of high leverage to finance the venture is modeled. Under certain circumstances, an RDLP may be an advantageous mechanism for investing in space commercialization.

## I. INTRODUCTION

The prospect of space commercialization [1,2] is alluring because of the outstanding potential associated with exploring new fields. Yet industry is by no means stampeding to get aboard the Space Shuttle, despite the favorable terms offered by NASA. It is therefore appropriate to ask why this condition prevails [3,4].

Factors such as a lack of knowledge of what is feasible today constitute an obstacle to commercialization, and NASA is moving to alleviate that condition. Another major obstacle is the very long lead times associated with space ventures, and this leads directly into the theme of this paper. The fact is that, when examined by the standard financial-analysis methods commonly used today, most space commercialization investment opportunities do not look sufficiently attractive to secure the corporate commitment needed to persevere over a long gestation period. Entering a space-commercialization enterprise requires a CEO decision to start down a new path; a predisposition to apply financial analysis methods to future business opportunities in space will quite likely militate against such decisions.

How profitable does a space venture have to be in order to compete with other conventional investment opportunities? In order to provide a quantitative answer to this question, we have carried out a series of return-on-investment calculations for a typical hypothetical

investment in an R&D program that leads to a new product produced in space. The investment provides a very generous stream of profits for 10 years or more. Nevertheless, the detailed analysis of the discounted after-tax cash flow associated with this investment reveals why the typical industrial investor has only limited enthusiasm for the opportunity to commercialize space.

It must be recognized at the outset that one single hypothetical example cannot possibly represent all the different possibilities. Still, the merit of this example is in showing how the perception of an industrial manager is affected by long lead times, so that even the most lucrative investments deflate to ordinary size when several years of front-end R&D is required before profits begin to accrue.

Section II of this paper describes the proposed investments. Section III presents the calculated Internal Rate of Return (IRR). Section IV shows how certain changes in financing and/or tax policy might alter the IRR. Section V briefly considers the effects of uncertainty. Section VI is a summary.

## II. THE HYPOTHETICAL INVESTMENT

We assume a 21-year program that begins with 3 years of research, 5 more years of development, tests, initial shuttle flights and perfecting the process (the space equivalent of what on earth would be the pilot plant phase), and 13 additional years of profitable manufacturing of the product in space. This timetable is reasonable for a product that begins with a genuine breakthrough in technology and goes on to either create a new market or dominate an existing market.

The product envisioned by the research staff is a metal-matrix composite involving cobalt, manganese and tungsten, having exceptional strength and uniformity. Making it requires liquid tungsten (temperature 4000°K) to be contained for many minutes during production, in the absence of any magnetic fields. As such, no earthbound containment system is acceptable, and so the entire operation must be carried out in the weightlessness of orbit. (Readers more comfortable with pharmaceuticals or semiconductors can readily make the adjustment to apply the numbers in this case to examples drawn from their own fields of interest.)

The initial research phase leads to a go/no-go decision before embarking on major hardware expenditures. The costs are \$150,000, \$450,000 and \$800,000 in the first 3 years. If the decision is made to go ahead, then in year 4, as spaceflight hardware begins to enter the picture, R&D costs total \$2.6 million. Year 5 requires \$5 million in R&D costs and \$5 million in capital investment. Year 6 (when the first two launches occur) required \$8 million in R&D costs and \$12 million in capital investment. This concludes the R&D phase. A second go/no-go decision occurs at this point. If the initial space flight tests are successful, then the certainty of profitability downstream is assured, and so the decision is made to move forward with a major commitment of capital and hardware construction.

As refinement of production moves forward, we hypothesize for year 7 a major input of capital equipment totaling \$30 million, accompanied by engineering costs of \$10 million. In year 8, with full scale production nearing readiness, additional capital requirements are only \$10 million, but now there are \$15 million in engineering costs.



The total face-value cost up to this point has been \$57 million in capital expenditures, \$17 million in R&D, and \$25 million in engineering costs. Table I summarizes these expenditures. At this point the company has spent almost \$100 million (over 8 years) but has not yet seen any profits.

TABLE I. CASH FLOW STREAMS ASSOCIATED WITH PRODUCTION OF NEW MATERIAL IN SPACE

YEAR	R&D COSTS	START-UP ENGINEERING	CAPITAL EXPENSES	PROFITS
1	\$150,000			
2	450,000			
3	800,000			
4	2,600,000			
5	5,000,000		5,000,000	
6	8,000,000		12,000,000	
7		10,000,000	30,000,000	
8		15,000,000	10,000,000	
9		10,000,000		32,000,000
10		7,500,000		56,160,000
11		4,080,000		60,600,000
12		2,720,000		65,500,000
13		1,820,000		70,740,000
14		1,210,000		67,740,000
15		810,000		57,580,000
16		540,000		48,940,000
17		360,000		41,600,000
18		240,000		35,360,000
19		160,000		30,050,000
20		110,000		25,550,000
21		70,000		21,710,000

Once begun, the stream of profits is generous indeed. After a 6-month shakedown period, the process for making the metal-matrix composite is fully operational in space, and partway into year 9 a stream of profits begins to occur.\* The product quality is so great that the corporation's marketing department estimates that the metal-matrix composite will capture 85% of the market for electric motor bearings, even at a high selling price. As a result, the total profit is expected to be \$56 million per year in the first full year of operation. After that, profits are expected to escalate 8% per year for the next 4 years, owing to a combination of inflation and greater acceptance by customers.

\* Over the next several years of profitable operations, engineering costs will decline steadily as bugs are worked out of the system: \$10 million in year 9, \$7.5 million in year 10, \$4 million in year 11, and declining 33% annually thereafter.

Beyond this point, it is conservatively assumed that competitors will somehow enter the market, so that profits fall 15% per year for the following 8 years. Actually, it makes very little difference what the profits do in the out-years, because the discount rate reduces them to small fractions of their face value anyway. Thus long-range uncertainty is not disruptive of investment planning calculations done today. The profit stream is also presented in Table I.

This hypothetical case can be criticized on a variety of points. For example, no description has been given as to what the capital expenditures are for. Moreover, expenditures for working capital have been ignored, and perhaps some part of the engineering and start-up costs may be capitalized and then depreciated. Addressing these issues would clutter the example with details, and would detract from the point of the paper, which is that long lead times before profitability exert a very inhibiting effect upon R&D commitments. Virtually all concepts whose goal is sustained processing of materials in space have such lead time associated with them. In this respect, the example is typical of space commercialization ventures.

### III. INVESTMENT EVALUATION

In evaluating any proposed investment, a dollar received in the future must be discounted at an appropriate rate to determine its present value today. Beyond this, one can choose from a variety of evaluation indices, including the Net Present Value (NPV), Internal Rate of Return (IRR), Equivalent Rate of Return (EqRR), and profitability Index (PI). The Internal Rate of Return is that discount rate at which the net present value of initial outlays and later profits sums to exactly zero [5].

In this paper we choose the IRR, because it is the most popular index used by corporate finance departments. Typically, in today's economy, corporations seldom invest in projects with an IRR below about 30%, even though the cost of borrowing money is down around 15%. This is because "mandatory" investments (those needed to keep the company running) have the first priority for capital, regardless of their IRR. As a result, "discretionary" investments (including R&D and ventures into new markets) reside far down the list. For most companies, so many investments are available each year that total levels of investment are capped by cash flow limitations [6]. As we shall see, this condition beckons to third-party financiers to engage in joint ventures with companies whose ideas are stymied by such limitations.

As the discount rate increases, the significance of front-end expenditures is enhanced, and returns in later years fade into oblivion. Table II illustrates this point by tabulating the appropriate multiplying factors for several years for discount rates of 10, 20 and 30%. In year 8, for example, a dollar is worth 51 cents, 28 cents, and 16 cents. The manager concerned with "bottom-line performance" cannot realistically have a horizon longer than 5 years when choosing among investment opportunities that offer IRRs above 30%.

TABLE II. DISCOUNT FACTORS FOR CERTAIN RATES

$d = \text{rate, } n = \text{year number, } f = 1/(1+d)^{n-1}$

YEAR	10%	20%	30%
1	1.0	1.0	1.0
2	.909	.833	.769
3	.751	.694	.592
4	.683	.579	.455
5	.621	.482	.350
8	.513	.279	.159
10	.424	.194	.094
15	.263	.078	.025
20	.164	.031	.007
21	.149	.026	.005

Evaluation Indices other than IRR are more appropriate for projects that are lucrative but long term. The manager who is concerned with the long term realizes that the cost of capital\* ultimately sets the hurdle rate, and computes the Net Present Value (NPV) of a long term project using that discount rate. This is the only way a long term project that requires continuing initial investment can survive the screening process.

Nevertheless, the IRR is still the index used by the great majority of American corporations when evaluating proposed R&D projects. Therefore it is the best choice to illuminate our understanding of corporate decision making. For the cash flows presented in Table I, the calculated IRR is 30.7%. Of course, this is the pre-tax IRR, which is only of significance to corporations that pay no taxes.

The after-tax IRR is calculated by including depreciation and tax credits, and by using a Federal tax rate of 46% with a state tax rate of 4%. The investment Tax Credit (ITC) is 10% of the capital expenses each year. Depreciation follows the ACRS rules for equipment (5-year schedule), but depreciation does not begin until year 8, at which time the entire \$57 million capital investment is eligible. This set of conditions yields the dollar amounts presented in Table III. The after tax cash flow is discounted at whatever rate is necessary to give a NPV of zero, and this rate is the after tax IRR.

TABLE III. AFTER TAX CASH FLOW CALCULATION – FUNDING ALL FROM EQUITY – MILLIONS OF DOLLARS

Year	Pretax Cash Flow (from Table I)	Taxable Income	Tax Owed	Tax Credits	After Tax Cash Flow	Cumulative ATCF (Discounted at 27.8%)
1	-.15	-.15	-.07	0.	-.08	-.08
2	-.45	-.45	-.22	0.	-.24	-.26
3	-.80	-.08	-.38	0.	-.42	-.52
4	-2.60	-2.60	-1.25	0.	-1.35	-1.17
5	-10.00	-5.00	-2.40	0.50	-7.10	-3.83
6	-20.00	-8.00	-3.84	1.20	-14.96	-8.23
7	-40.00	-10.00	-4.80	3.00	-32.20	-15.64
8	-25.00	-26.40	-12.67	1.00	-11.33	-17.67
9	22.00	3.76	1.80	0.	20.20	-14.83
10	48.66	34.98	16.79	0.	31.87	-11.31
11	56.58	47.46	22.78	0.	33.80	-8.40
12	62.78	58.22	27.94	0.	34.83	-6.04
13	68.92	68.92	33.08	0.	35.84	-4.15
14	66.52	66.52	31.93	0.	34.59	-2.71
15	56.77	56.77	27.25	0.	29.52	-1.76
16	48.40	48.40	23.23	0.	25.17	-1.12
17	41.24	41.24	19.79	0.	21.44	-.69
18	35.12	35.12	16.86	0.	18.26	-.41
19	29.89	29.89	14.35	0.	15.55	-.22
20	25.44	25.44	12.21	0.	13.23	-.09
21	21.64	21.64	10.39	0.	11.25	-.01

\* A weighted average of the borrowing rate (15-16%) and the return expected on stockholder's equity (25-30%).

For our hypothetical example, the IRR is 27.8%. This is a very disappointing figure for an investment with such a high profit potential, but it must be recognized that, for example, the \$33.8 million after-tax gain of year 11 is only worth \$2.9 million in today's dollars when discounted at 27.8%. By contrast, the investor who calculates NPV with a fixed corporate discount rate of 15% would find that same \$33.8 million contributing \$8.4 million in today's dollars. Figure 1 displays the variation of after tax NPV of this project with increasing discount rate. The curve crosses the horizontal axis at the IRR, and the NPV changes from gain to loss there.

Because of the long waiting time for profits to begin flowing, the NPV of this project is quite volatile to changes in the discount rate. For projects with a much shorter time horizon, the NPV is less dependent upon later years, and hence less affected by discount rate. It is not difficult to construct a 5-year project with an IRR above 30% but a smaller NPV (at 20%) than this project's. The NPV line for the alternate project would then cross the curve of Figure 1 somewhere around 22 or 25%. If IRR were the main decision-criterion, the short-term project would be chosen; but if Profitability Index (PI) or NPV (at 20% opportunity cost of money) was used, the space-manufacturing project would win out.

#### IV. EFFECT OF CHANGES IN TAXES OR FINANCING

American space policy recognizes as a goal the desirability of encouraging the private sector to commercialize space [7]. Often it has been the custom to use the tax laws as an instrument of policy, so it is worth considering how potential investors looking at this space-commercialization project would respond to changes in tax law.

One such change occurred in 1981, when a 25% tax credit was offered to companies who increase their R&D expenditures in a year [8]. Our hypothetical case was first analyzed without that tax credit, which gave an IRR of 27.8%. When a 25% tax credit was given for the research expenses of the first 3 years, the IRR rose to 28.4%. This difference may seem inconsequential, but remember that the total spending in the first 3 years accumulated to only \$1.4 million out of a \$100 million project. The fact that this tax credit has any effect at all is because it occurs in the early years. Had a 25% credit been applied to the entire 6-year span of R&D, the effect would have been much greater.

Another possibility that is often discussed in Congress is the use of targeted tax credits [6]. For example, the law might be amended to provide an additional 10% tax credit for capital investments in space manufacturing. Our calculations indicate that such a change in tax law would increase the IRR by less than 2 percentage points, hardly enough to motivate a hesitant investor.

Alternate forms of financing now available in the private sector are likely to be more persuasive than government tax changes. Leveraging of investments is possible through a variety of new techniques. To model this, we considered the case in which \$40 million out of the total of \$57 million in capital costs was obtained from an external financing source. The \$40 million is borrowed in the middle of year 7, at the rather high fixed interest rate of 20%, to be paid back uniformly over 8 years. An 8-year finance lease might be one example of such financing. It is incidentally assumed that this new debt will not adversely affect the corporation's bond rating or otherwise drive up its cost of borrowing. This is done to keep the example simple. Such "project financing" would not be typical of major corporations, but might represent the behavior of an R&D Limited Partnership (RDLP) formed explicitly for this venture.

Table IV shows the cash flow for this split-financed case. The presence of \$820,000 monthly payments (part principal, part interest) beginning in the middle of year 7 reduce the operating cash flow in the early profitable years, but the very tiny capital outlays in years 7 and 8 compensate for this. Thus cash flow is smaller in each year 7-15 (i.e., less negative in 7 and 8, less positive thereafter). This causes a small pretax improvement, and a large after tax improvement. As a consequence of external financing, the IRR jumps up to 34.0%, compared to 28.4% in the unleveraged case. To investors with other options to choose from in the 30% IRR range, this difference may be significant.

TABLE IV. AFTER TAX CASH FLOW CALCULATION – FUNDING INCLUDES \$40 MILLION BORROWED CAPITAL – MILLIONS OF DOLLARS

Year	Pretax <sup>‡</sup> Cash Flow	Taxable Income	Tax Owed	Tax Credits <sup>*</sup>	After Tax Cash Flow	Cumulative ATCF (discounted at 34.0%)
1	-.15	-.15	-.07	.04	-.04	-.04
2	-.45	-.45	-.22	.11	-.12	-.13
3	-.80	-.80	-.38	.20	-.22	-.25
4	-2.60	-2.60	-1.25	.00	-1.35	-.81
5	-10.00	-5.00	-2.40	.50	-7.10	-3.01
6	-20.00	-8.00	-3.84	1.20	-14.96	-6.47
7	-14.95	-13.87	-6.66	4.00	-4.29	-7.21
8	-24.89	-34.50	-16.56	0.	-8.33	-8.29
9	12.11	-4.21	-2.02	0.	14.13	-6.93
10	38.77	27.95	13.42	0.	25.35	-5.11
11	46.68	41.52	19.93	0.	26.75	-3.68
12	52.88	53.55	25.71	0.	27.18	-2.60
13	59.03	65.74	31.56	0.	27.47	-1.78
14	56.63	64.83	31.12	0.	25.52	-1.22
15	51.82	56.57	27.15	0.	24.67	-.81
16	48.40	48.40	23.23	0.	25.17	-.50
17	41.24	41.24	19.79	0.	21.44	-.30
18	35.12	35.12	16.86	0.	18.26	-.17
19	29.89	29.89	14.35	0.	15.55	-.09
20	25.44	25.44	12.21	0.	13.23	-.04
21	21.64	21.64	10.39	0.	11.25	-.01

<sup>‡</sup> Includes monthly payments of \$.82 million in years 7-15

<sup>\*</sup> Includes 25% R&D Credit for years 1-3.

The driving force that makes the leveraged investment more attractive is that money borrowed at 20% is earning a substantially higher rate. Every homeowner experiences the same advantage: when the house increases 10% in value, if it is 75% mortgaged, the homeowner's return on equity is 40%. The tax deductibility of interest payments mitigate the burden of the 20% interest rate for the RDLP or leveraged corporation.

Combinations of leveraging and government support enhance the attractiveness of the investment still further. For example, a 10% additional tax credit adds 4 percentage points to the IRR; and a government-subsidized loan at 10% instead of 20% adds 1.6 percentage points.

Table V collects and summarizes the several variations upon the original example. The essential point to be grasped from all this financial discussion is that there is an incentive for the leveraged investor (RDLPs, joint ventures, etc.) to participate in space commercialization. The same opportunity in space carries a disincentive to the equity-funded investor (or large corporation relying upon conventional IRR analysis) because of the exceptionally long lead times associated with R&D ventures in space.

TABLE V. IRR UNDER VARIOUS OPTIONS

BASE CASE	27.8%
with 25% tax credit on R&D portion	28.4%
Unconventional Financing	
2/3 of capital borrowed at 20%	34.0%
Subsidized Loan	
2/3 of capital borrowed at 10%	35.6%
Additional 10% tax credit	
All Equity Financing	29.6%
2/3 of capital borrowed at 20%	33.6%

## V. RISK

So far, the example has treated the various cash flow items as fixed and certain, when in reality, the project is encumbered with considerable uncertainty. The cash flow is by no means definite, especially in later years. Risk goes both ways: profits may not materialize, or they may be greater than expectations, or hold up longer.

There are two points where a go/no-go decision is made, and we have only looked at the outcome when the decision is "go." Were the project to be stopped at either of those points, the total preceding expenditure would be lost. The estimated return on investment should be lowered in order to compensate for that possibility.

The proper treatment of risk is the subject of an extensive literature [9]. Here we only observe that the size of the corporation strongly influences their ability to bear risk. For a large company in which an R&D Expenditure of \$1.4 million is small, the simple "expected value" method of predicting NPV is adequate. For a small company, the penalty for failure may be bankruptcy, in which case their perceived risk will be much higher and their approach far more hesitant.

The expected value method is relatively simple: here the cash flow in each year is multiplied by the probability that the project is still ongoing in that year. The resulting NPV or IRR is the expected value of the NPV or IRR. Referring to our example, suppose that the probability is 1/2 that the first R&E hurdle will be overcome, and hence the project will proceed beyond 3 years. Assume further that at the second go/no-go point, the decision is made to go ahead. But then let the probability be only 1/2 that the profits will materialize as predicted – this corresponds to a cautious guess about the market share that can be captured with the new space-produced alloy. To represent this, the cash flows in Table I would be revised by multiplying the first 3 values by 1, all subsequent costs by 1/2, and all the profits by 1/4. The expected value of the NPV can be termed the “utility” of the investment [10]. Obviously the expected value of any index of performance will decline sharply.

We have modeled this “expected value” case and calculated the after tax IRR to be 15.7%, a precipitous drop from the “sure-thing” figure of 28.4%. If the investment is leveraged as described in the preceding section, Table III has to be similarly revised and the resulting after tax IRR is 17.6%, down from 34%. For such a return, borrowing at 20% becomes of questionable value. However, given the freedom to bail out after 3 years with only a \$1.4 million loss, the question posed to either investor by these expected value calculations is “Am I willing to invest \$1.4 million to reach that first decision point?” For such an R&D-level decision, an expected return of 15-18% is not too bad.

When a company cannot afford to lose big, they are not likely to enter into a project such as this. Consider a medium-sized company in which a \$1.4 million R&D loss is tolerable, but a \$34 million loss (the total cost of reaching the second go/no-go decision point) is not. Assume the company’s survival is seriously threatened by such a loss. In that case, the weighted value of the various outcomes will greatly distort their outlook on this project. The utility of the expenditures in years 4 through 6 will be so large and negative that the utility of the entire project (the weighted expected value of the NPV) will be negative. Thus for this company the proper decision at the outset is not to pursue the project.

Down-side risk is not the only kind of uncertainty; the possibility of some major scientific breakthrough is equally important. Yet very few business investors give any weight to concepts like the value to future generations. Such very long term risks and rewards belong to the entire society.

Finding ways to encourage medium-sized companies to take risks puts us at once into questions of public policy [4]. Such avenues as loan guarantees, research grants, and free flight opportunities offered by NASA, all fall within that category. Here it suffices to note that the weighted value of risk is an extra disincentive to all but very large corporations.

## VI. SUMMARY

By following a single hypothetical example through a series of variations, we have described how different potential investors might look at the opportunity to participate in space commercialization. The viewpoints represented include those of large and small, equity-based and leveraged investors.

The example itself is fairly typical of commercial opportunities in space. The chief characteristics are a steadily increasing requirement for capital infusion over an 8-year period,

followed by a very generous stream of profits running another decade or more beyond. There is a decision point at 3 years, at the conclusion of laboratory R&D; and another at 6 years, following 2 initial space flights.

Many companies compute the Internal Rate of Return (IRR) enroute to evaluating an investment opportunity, and this has been done here. The IRR is constrained from becoming very large by the long lead time for profits; the value of distant dollars is reduced to insignificance as the IRR nears 30%. For this project, the Net Present Value (NPV) responds sharply to changes in the discount rate, as shown in Figure 1.

Changes in government tax policy have been analyzed as well. The new R&D tax credit is not important, because R&D is a small fraction of the total project cost. An additional 10% tax credit for capital invested in space ventures is not persuasive, either. However, creative new financial coalitions, such as RDLPs, may be able to take advantage of leveraging to facilitate venturing into space.

The uncertainty of R&D directed towards space must not be minimized. Large companies can afford to take risks of the magnitude of a space venture; medium and small firms cannot. The advantage of RDLPs is particularly noteworthy here: on the one hand, a total loss is acceptable if unpleasant; and on the other, the partners can leverage their individual investment shares. Uncertainty and leverage together increase the volatility of return-on-investment, but RDLP investors are cognizant of that and willingly accept risk.

Certain recommendations are implicit in the results of these calculations. First, industrial leaders should take an imaginative and long-range view when considering space investments, and calculate the NPV of projects instead of the IRR. For its part, NASA should maintain its outstanding record of reliability for the Shuttle, resist delays vigorously, and move swiftly to accommodate companies getting ready to fly.



## REFERENCES

1. "Civilian Space Policy and Applications" (Office of Technology Assessment, US Congress, OTA-STI-177, 1982); Superintendent of Documents, U.S. Government Printing Office, Washington, DC, 20402.
2. "Encouraging Business Ventures in Space Technologies," report by National Academy of Public Administration (Washington, DC: 1983).
3. R. A. Williamson, "The Industrialization of Space: Prospects and Barriers," *Futures* (Oct. 1982), pp. 405-416.
4. "Policy and Legal Issues Involved in the Commercialization of Space" Committee Print 98-102, U.S. Senate Committee on Commerce, Science and Transportation, September 23, 1983.
5. R. Brealey and S. Myers, Principles of Corporate Finance (McGraw-Hill, 1981).
6. "Industrial Energy Use" (Washington DC; U. S. Congress, Office of Technology Assessment, OTA-E-198, June 1983), Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.
7. State of the Union Address, Ed. by President Reagan, (January 1984).
8. P.L. 97-34, Economic Recovery Tax Act of 1981 (ERTA).
9. See, for example, V. Chankong and Y. Y. Haimes, Multiobjective Decisionmaking: Theory and Methodology (North Holland: 1983).
10. Risk Benefit Analysis in Water Resources Planning and Management, Y. Y. Haimes, Ed., (Plenum Press: 1981).

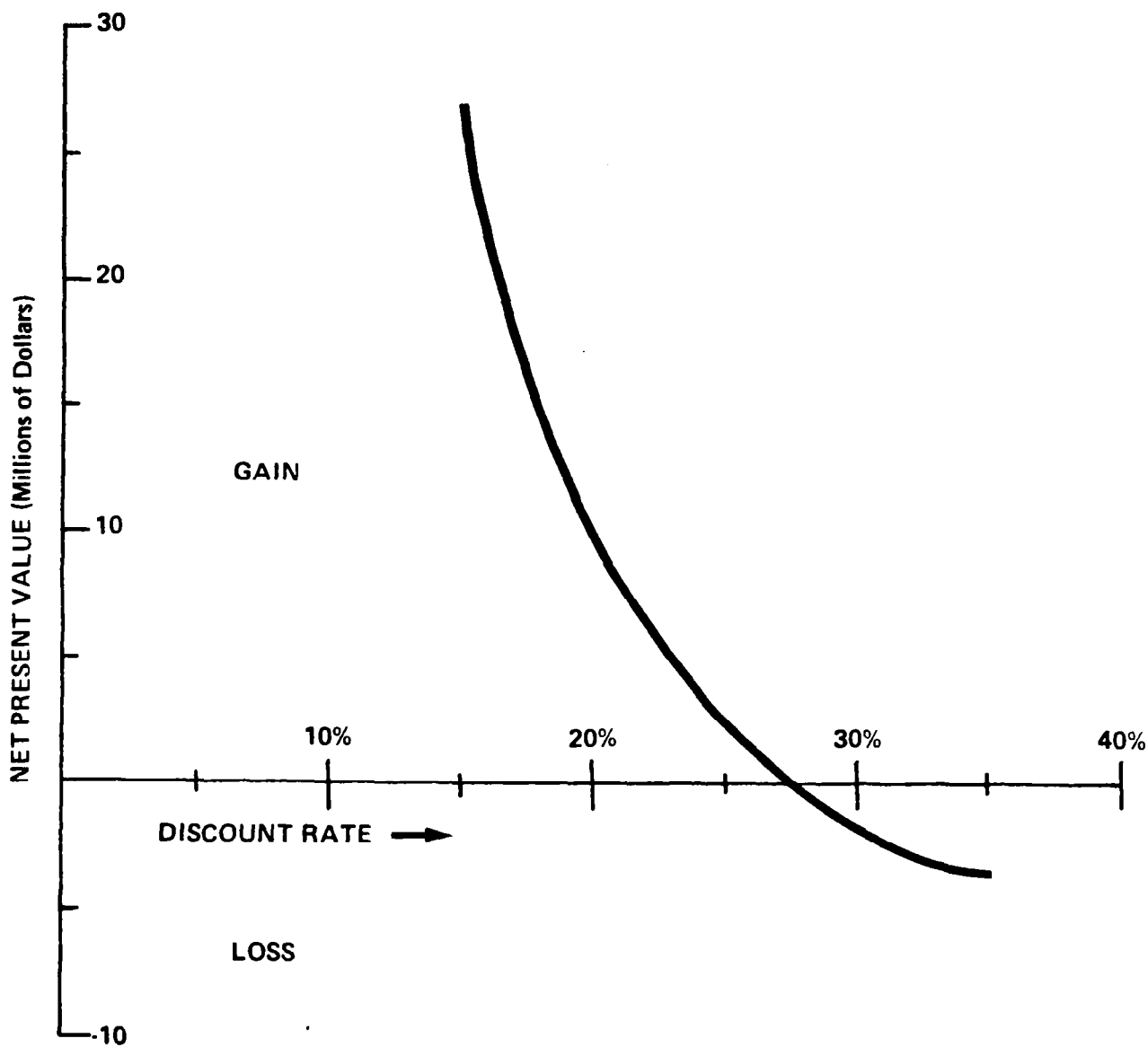


Figure 1 EFFECT OF DISCOUNT RATE ON NPV

# DESIGN AND IMPLEMENTATION OF A LOW-GRAVITY SOLIDIFICATION EXPERIMENT PACKAGE FOR THE F-104

by

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## ABSTRACT

The use of the F-104 Interceptor at Dryden Flight Research Facility for low-gravity materials processing experiments has been extended to include alloy solidification studies above 1000°C. The F-104 can provide up to 60 seconds of low-gravity, but requires a unique experiment package for integration into the aircraft, both physically and electronically.

This paper describes the current research with the F-104 experimental furnace system which has been used to process cast iron samples for the John Deere Company. Results of these test are shown to demonstrate the capability of the facility and its operation.

## DISCUSSION

The F-104 Solidification Experiment Package is a semiautomatic self-contained system designed to melt down particular alloys during the flight ascent of the F-104 aircraft and subsequently during the low-gravity maneuver ( $10^{-1}$  to  $10^{-3}$  g's) to quench the sample so as to allow solidification of the alloy in a low gravity environment. The system is basically a high temperature furnace controlled by an Omega automatic type S temperature controller, a pressurized helium quench system, and a signal conditioning circuit designed to amplify the millivolt signal coming from the S thermocouple up to a voltage level suitable for telemetry transmission to the ground.

All electronics are designed or have been modified to operate with the 28 VDC supplied by the aircraft or the  $\pm 15$  volts supplied by the power converter in the package. The Omega Model 6103 temperature controller has been modified to operate with +15 volts DC while the Analog Device AD522A signal amplifier uses both  $\pm 15$  volts DC. The Ohmic model JR 125 reference cold junction is battery powered and is energized via a control relay. This unit is self-contained in that it contains its own internal battery rated for 5000 hours of operation.

For the current application the package is calibrated to meet the needs of experiments desired by the John Deere Company. These experiments require the furnace to attain a temperature of  $1350^{\circ}\text{C} \pm 10^{\circ}\text{C}$  and maintain that temperature for no less than 2 minutes and no more than 10. Once the furnace is energized on command from the co-pilot it takes less than 11 minutes to reach the maximum temperature of  $1350^{\circ}\text{C}$ . These values can vary  $\pm 2$  minutes depending on sample type and voltage conditions of the aircraft. A typical flight run would include the co-pilot activating the furnace via a toggle switch on his instrument panel about 16 to 18 minutes prior to entering his low-gravity maneuver. Then  $30 \pm 5$  seconds prior to entering low gravity the co-pilot would turn the furnace off and activate the quench solenoid valve via a second toggle switch. With the solenoid valve now open, helium will flow at a present rate around the furnace and cool the cast iron sample at a controlled rate. If the timing is correct the sample should solidify during the optimum low-gravity period. This period is a 40 second window in the middle of the total 60 second maneuver. The first and last 10 seconds are considered poor low gravity due to wing rock of the aircraft. Once the furnace is turned off only data acquisition occurs and the helium valve is left open until the supply tank is exhausted. Upon landing, the experiment package is removed from the aircraft and the processed alloy sample is then replaced with a new one.

Figure 1 pictures the loading of the F-104 experiment package into the "E" bay of F-104 No. 825. Originally this bay was loaded with navigational equipment packages. Overall size limitations are 22" L x 16" H x 14" W and approximately 50 pounds. The only power available to the package is 28 VDC at 30 amps.

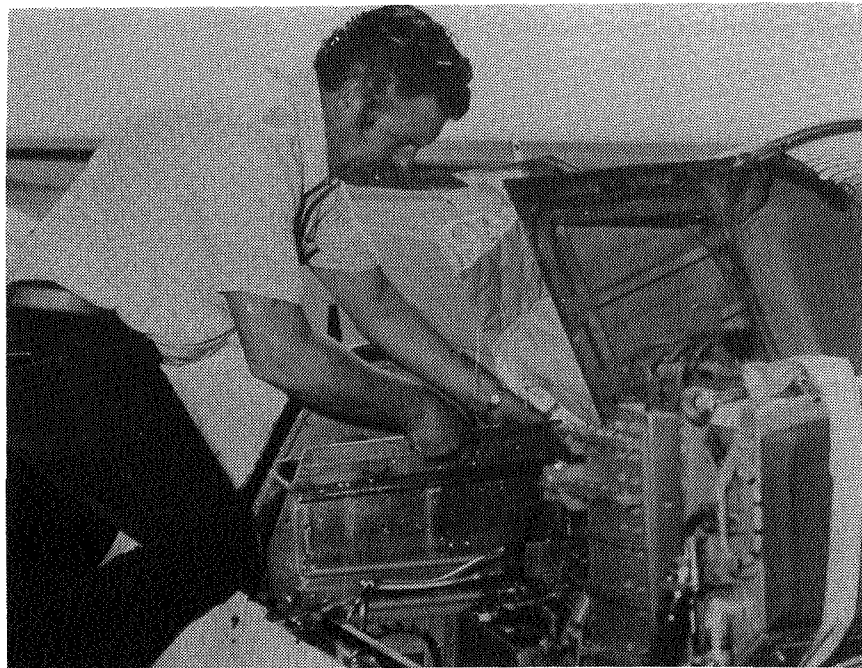


Figure 1

Figure 2 displays the package as it sits in the "E" bay.

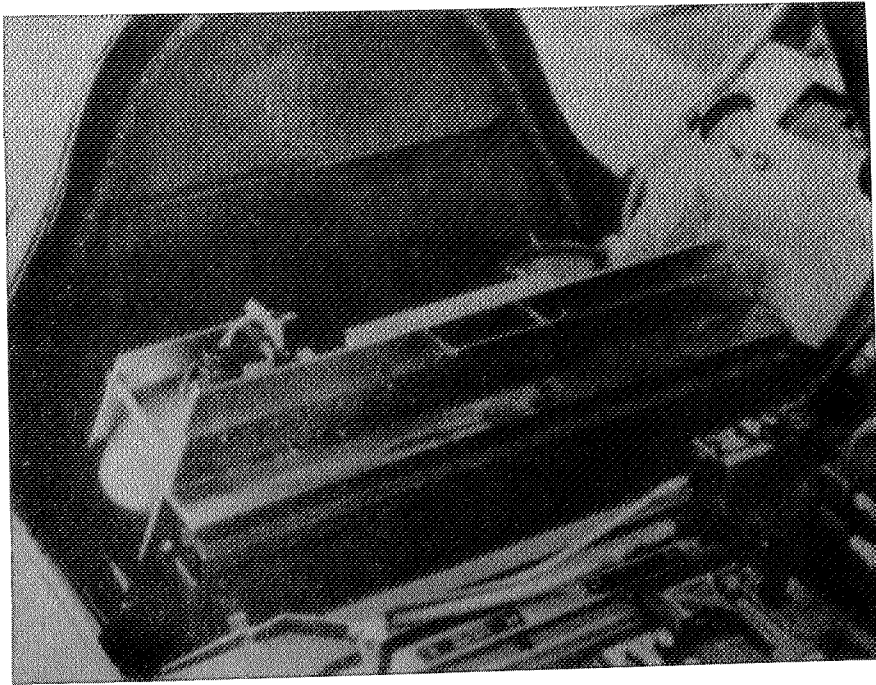


Figure 2

Sample temperature and accelerometer data are telemetered from the aircraft to the mobile telemetry van where it is recorded on digital tape and strip charts. Close monitoring of the temperature data and direct voice contact with the pilots allows for the required timing logistics. Pictured in Figure 3 is one of the Dryden engineers noting major events on the strip charts.

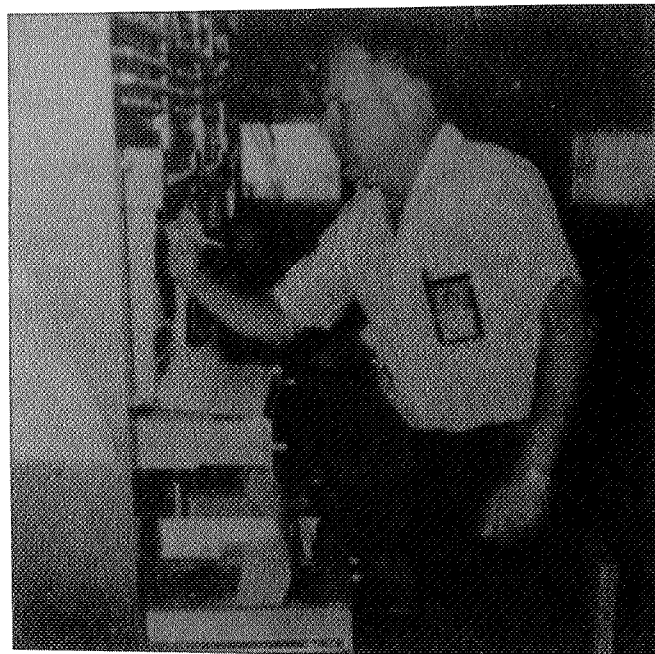


Figure 3

F-104 No. 825 is a two seat aircraft and it takes both the pilot and the co-pilot to fly it. During the maneuver g forces may reach 3-g's during pull up and pull out. Because of this the front pilot must use both hands to maneuver the aircraft and the co-pilot controls the engine throttle. Due to the possibility of an engine flame-out the pilots must be ready at all times to perform a dead stick landing on the dry lake bed.

Figure 4 shows the two pilots getting ready for flight. During the low-gravity maneuver of the aircraft altitudes may reach as high as 72,000 feet. As a result the pilots must wear special pressure suits and require the full support of life support systems.



Figure 4

The two diagrams in Figure 5 represent typical gravity levels experienced by the aircraft and experiment package during a low-g maneuver. The top graph is an actual strip chart recording taken during a low-g maneuver. The lower graph gives a broader perspective.

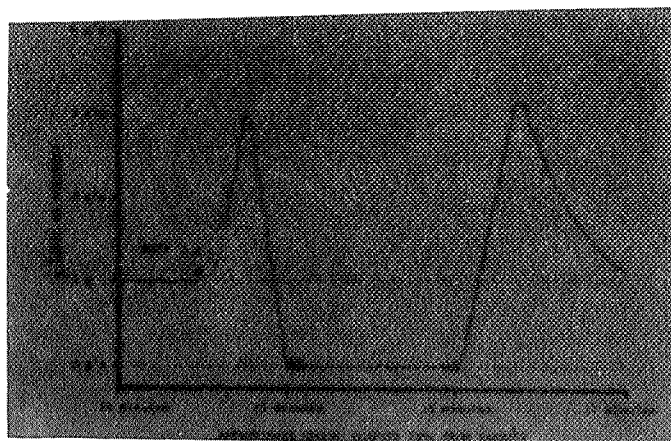
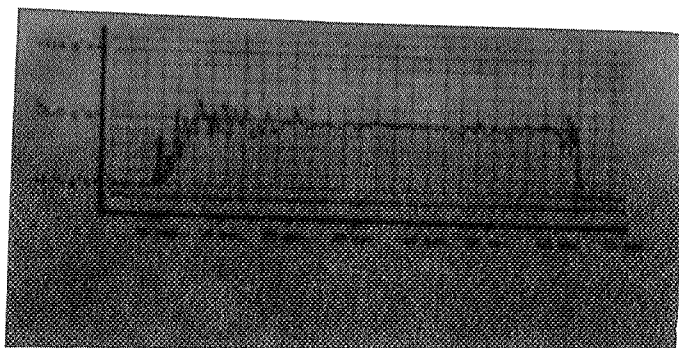


Figure 5

Figures 6 and 7 are photomicrographs with their cooling curves of nodular cast iron processed in the F-104 experiment package during normal 1-g gravity. The cast iron is of nodular type supplied by the John Deere Company who currently has a technical exchange agreement with the Marshall Space Flight Center. The sample alloys were processed at the Johnson Environmental and Energy Center, UAH, and represent only a small part of the ground based testings of the F-104 experiment package. It was through these based runs that it was discovered that the effects of localized chilling was caused by the methodology used in quenching the processed samples. Figure 6 micrographs show 100% nodular iron which was quenched at a rate of 76°C/minute. Figure 7 is of the same alloy only quenched at a faster rate of 261°C/minute. It can be seen clearly that sample is no longer 100% nodular but rather 20% nodular grey and 80% white iron. Since then a major modification in the quenching system was implemented. By changing the flow characteristics of the helium gas, subsequent tests have shown a major reduction in the chill zones and white iron formation. Samples have been quenched as fast as 200°C/minute with little or no white iron formation and no chill zones. The first time the F-104 experiment package was flown this problem had as yet not been discovered and as a result the processed samples were difficult to interpret.

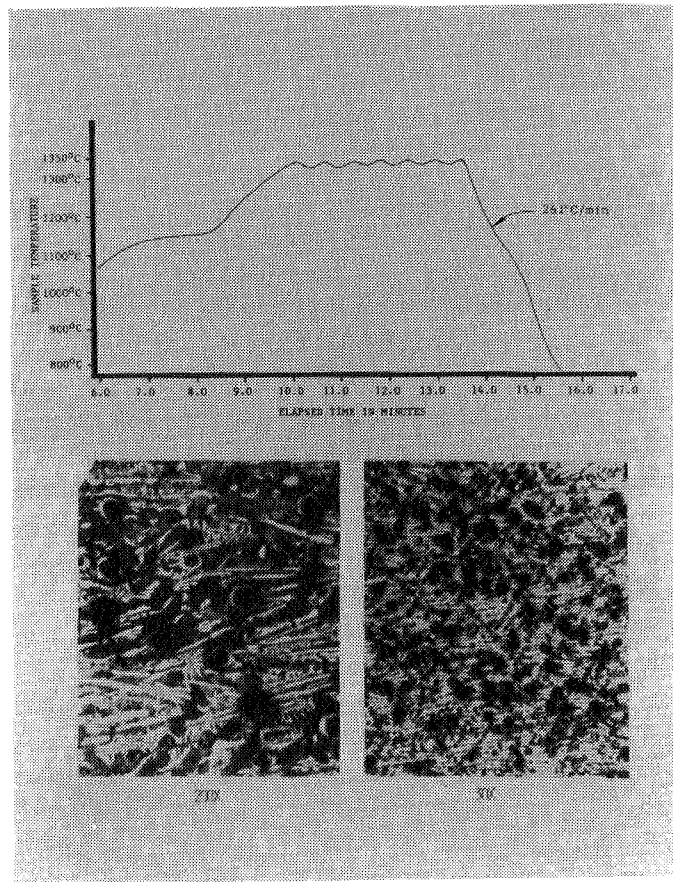


Figure 6

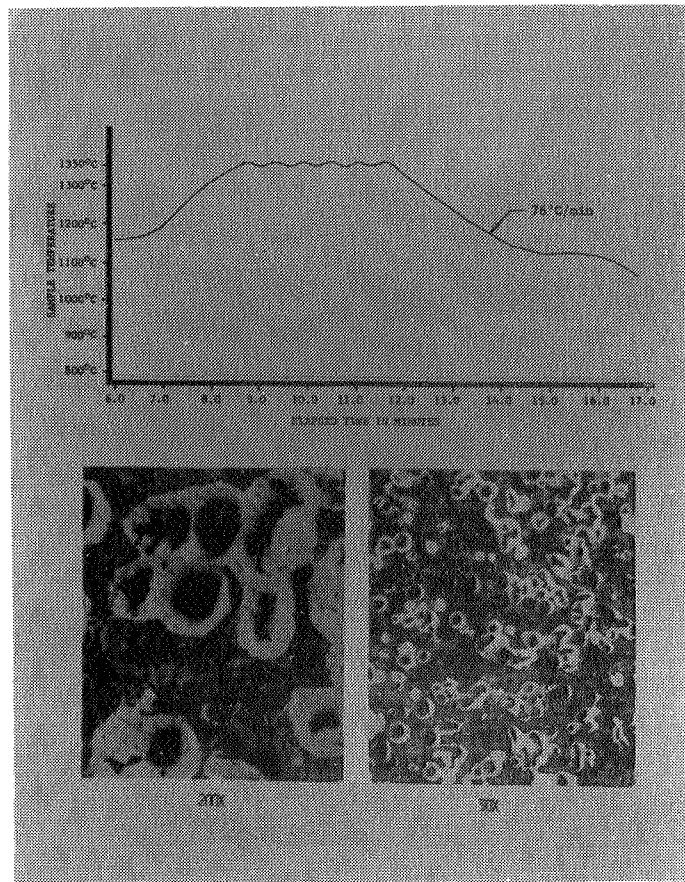


Figure 7



# ADVANCES IN ELECTROPHORETIC SEPARATIONS

by

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## ABSTRACT

During the past several years, NASA has investigated free-fluid electrophoresis using laboratory and space experiments combined with extensive mathematical modeling. These experiments have confirmed that buoyancy-driven convective flows due to thermal and concentration gradients are absent in the reduced-gravity environment of space. The elimination of convection in weightlessness offers possible improvements in electrophoresis and other separation methods which occur in fluid media. The mathematical modeling has suggested new ways of doing electrophoresis in space and explained various phenomena that have been observed during past experiments. To assess the importance of this potential space application, NASA has investigated the extent to which ground-based separation techniques have been limited by gravity-induced convection and designed space experiments to evaluate specific characteristics of the fluid/particle environment. This has involved theoretical and experimental analysis of the flows in electrophoresis and other separation devices. It is anticipated that the results will suggest improvements in the devices used on Earth. Additionally, a series of experiments have been proposed that require weightlessness and apparatus is becoming available that can be used to carry out these experiments in the near future.

## OPPORTUNITIES FOR COMMERCIAL ORGANIZATIONS

by

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### ABSTRACT

One of NASA's objectives is to see aeronautical and space technology applied in ways which will result in benefits for the public. Recognizing that this can best be done through application of the technology to marketplace needs by private organizations, NASA is prepared to work with commercial organizations on a case-by-case basis to explore possible applications of technology of materials processing in low-gravity. Several avenues have been developed for commercial organizations to gain first-hand knowledge about the possibilities and limitations of this new technology.

An organization can obtain an initial understanding of materials processing research in low-gravity by reviewing on-going NASA-sponsored research. Once specific areas of interest are identified, joint investigations and joint endeavors can be developed. Joint investigations take a number of forms and involve conduct of low-gravity experimentation with exchange of technical information between the company and NASA. Company personnel may join in on-going investigations of mutual interest or may support areas for investigation.

Joint endeavors also involve low-gravity investigations but with a specific commercial goal. In joint endeavors, NASA and the private firm share the early cost and technical risks. Terms and conditions, including business arrangements, are negotiable and are commensurate with the risks, involvements, and investments of the parties.

NASA has established a special office to familiarize commercial organizations with materials processing in low-gravity. This office will provide information on present research and will, if requested, hold a seminar to present the technological and business aspects of joint investigations and joint endeavors to interested organizations. Also, arrangements can be made for visits to laboratories where ground-based research is in progress.

# SATELLITE SERVICING: A BUSINESS OPPORTUNITY?

by

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## ABSTRACT

We attempt to answer the question, "Is satellite servicing a sound business venture?" The approach taken was to derive the service rate which a user must be charged to yield a reasonable return and then to compare that rate against the market's willingness to pay it. Steps taken to provide the basis from which the service rate could be derived included: (1) constructing a hypothetical on-orbit servicing business offering both on-orbit and associated ground services, (2) estimating the total on-orbit service business potential by analyzing mission models to the year 2000, and (3) setting up ground rules to bound the conduct of the business. Using this basic information we estimated service demand (business volume), cost to set up the business, costs for operation and maintenance and then included tax rates and desired rate of return to determine the user charge. Sensitivity of the service rate to various parameters were also assessed. The time span for the business venture was taken from 1986 through 2000 with service to 1991 provided via the orbiter and by a space station beyond 1991. This point analysis shows about five years of negative cash flow, with steady profits thereafter.

# DOING BUSINESS IN SPACE: HOW TO GET THERE FROM HERE

by

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## ABSTRACT

Space represents a business frontier which may eventually overshadow such growing industries as telecommunications, microelectronics, and computers. The challenge facing American industry is to find the best means of developing this new frontier and reaping its rewards.

This paper presents a step-by-step process by which a company (or an individual) can find out:

- 1) How to identify the ways in which space may benefit them
- 2) How to identify and prepare the experimental work necessary to demonstrate the concept
- 3) How to arrange to carry out the experiment
- 4) How to continue development through a prototype to production
- 5) How to safeguard proprietary information throughout the process
- 6) How to carry out the entire process in the shortest time with a minimum of cost and risk
- 7) If necessary, how to locate and secure financing.

Forward looking technology-oriented businessmen and inventors will be directing their attention to space opportunities, and will want to find the most direct route to profits in space.

## INTRODUCTION

In response to President Reagan's announcement\* of a dual commitment to a permanent manned space station and to the commercialization of space, private sector companies and investors are looking much more closely at the opportunities afforded them by the various attributes of space. Despite the establishment of several ventures designed to exploit these unique attributes, it is still difficult to determine the best way to initiate and carry out such new ventures.

\* See excerpt to State of the Union Address, January 25, 1984, attached.

The purpose of this paper is to describe the step-by-step process through which a company can develop a commercial space mission from concept through production, with particular focus on making use of available cooperation from NASA. In order to illustrate this step-by-step process of Commercial Mission Development, exhibits have been prepared which deal with the three most common scenarios:

- o Exhibit I – Existing Enterprise – Space-based Production
- o Exhibit II – Entrepreneurial Ventures
- o Exhibit III – Existing Enterprise – Ground-based Production

Each of these exhibits has been designed to illustrate the steps through which a new space venture might be approached in each scenario. Certain alterations would have to be made depending on the specifics of the mission or missions involved.

The Commercial Mission Development process can be divided into five phases:

- o Concept Development
- o Feasibility Assessment
- o R&D Program
- o Prototype Development
- o Production

The following sections describe the process within each of these phases, as well as how this process differs among the three scenarios.

## CONCEPT DEVELOPMENT

### Existing Enterprise – Space-based Production

The development of any new commercial space mission must of course begin with a technical concept. Mission concepts often begin as broad technical areas of interest, such as “crystal growth” or “biological separations,” and may be generated either as a by-product of ongoing research within the company or from monitoring the activities of competitors.

With one or more broad mission concepts in mind, a company can perform some preliminary analysis to determine what specific concepts for space missions exist or have already been examined by others. The firm may also be able to derive new specific mission concepts within the same technical area through its own unique or proprietary skills. Once an array of several specific concepts has been assembled and analyzed, one or more preferred concepts may be selected as the most interesting ones for further consideration by the company. The identification of specific concepts from broad areas of interest is important for a company which already operates in a non-aerospace industry; because of the limited understanding of the attributes of space in many non-aerospace firms, the incentive for pursuing a venture may not

become obvious unless the specific benefits of a particular mission concept are examined. Without this examination of specific concepts, the general idea of a space venture may be improperly rejected out of hand.

Another source of specific mission concepts is a NASA-sponsored intermediary. Using its knowledge of specific space attributes and its familiarity with non-aerospace industries, a third-party intermediary can present firms with specific concepts tailored to their activities. Booz, Allen & Hamilton has developed this "seed concept" approach to commercial user development under its contract to NASA to provide intermediary services.

Once identified, the preferred mission concepts can then be compared with the long range goals of the company: "Would such a venture fit into our plans?" For those concepts which appear to be appropriate, a first cut can then be made at understanding the economics of developing and operating such a venture. This economic analysis must take into account both the potential market value of the product or service and the estimated cost of providing it. Development time and costs must also be taken into account, but to a certain degree some of these costs (particularly flight costs) may be offset through NASA's cooperative programs.

If the economics of the venture appear attractive, it now becomes reasonable to contact NASA to discuss the possibility of initiating a development program. Carrying out the preliminary economic analysis is important before talking with NASA since it can give the company an idea of the level of assistance it may wish to negotiate with the Agency, and what consideration of value to the Government it can offer in return. NASA has a variety of means available through which ground-based and space-based research and development can be carried out at a reduced cost to the firm. With the introduction of the Agency's new Commercial Space Policy, even more ways will be made available in which NASA may assist new users of space to develop mission concepts.

The contact with NASA may have several objectives. One of these might be to locate and talk with NASA scientists and engineers who have worked on some aspect of the preferred concept and thus may be able to provide further technical details. Another goal should be the identification of the relevant programs or agreements through which NASA might be able to assist the company. The most prominent of these agreements is the Joint Endeavor Agreement (JEA), under which NASA provides free Shuttle flights for the company during its R&D phase in exchange for some form of quid pro quo. One typical quid pro quo commits the company to processing some NASA samples with its experimental apparatus so that the Agency may further its understanding of space phenomena. Other forms of quid pro quo are likely to be developed as NASA's Commercial Space Policy is put into effect.

The first contact with NASA may be complicated by several factors. The first of these may be the proprietary nature of a company's concept. Companies often are reluctant to discuss specifics with NASA for fear of losing control of their concept. However, by working through an independent third party intermediary, a company can safeguard the proprietary portions of its concept while still carrying on a useful dialog with NASA.

A second factor complicating the approach to NASA is the difficulty in determining which NASA office or individual a company should contact. A number of offices at NASA Headquarters in Washington and at various NASA Centers around the country are involved in NASA's commercially-oriented activities. Identifying the appropriate office to deal with has been difficult in the past, but again the services of an intermediary have been useful to a number of firms in both finding the right office and initiating productive discussions.

Booz, Allen is presently under contract to NASA to function to assist private sector companies in their dealings with the Agency. In 1981, Booz, Allen developed the concept of an intermediary from its experience with private sector clients, and has been functioning in this role for NASA for over two years. A number of firms are presently working with NASA through Booz, Allen, several of which have entered into confidential agreements under which Booz, Allen buffers the proprietary portions of their concepts from NASA. In at least two cases (with NASA's cooperation), Booz, Allen has not yet revealed the firms' identities to NASA.

Under NASA's new Commercial Space Policy, a high level Office of Space Commercialization is to be established. As a focal point for coordinating the Agency's initiatives designed to stimulate, encourage, and assist potential new users of space, this office should greatly alleviate the problems which private sector firms have had in working with the Agency in the development of commercial space ventures.

### Entrepreneurial Ventures

For entrepreneurial ventures, the concept development process is very similar to that for an existing enterprise. But for new ventures, there are often no established long range business plans against which to assess the fit of the preferred concepts. In many cases the company is being formed specifically to pursue the space venture in question, and it is necessary to use the first cut economic analysis as a basis for establishing the company's long range goals, building a business plan around the concept and its economics.

### Existing Enterprise – Ground-based Production

For an existing enterprise interested in conducting space research to improve some aspect of its ground-based production process, the concept development phase is nearly identical to that for space-based production. The distinction is that the concepts which are considered and chosen are oriented toward a particular ground-based process for which space research may hold the key to significant improvements. The comparison with long range goals is not essential because the space venture is likely to be a straightforward extension to the firm's R&D program. For a similar reason, combined with the absence of an expensive space production phase, the economics will probably be simpler.

### Summary – Concept Development

The concept development stage is an important first step in any venture, particularly for a space venture where a company or individual may be unfamiliar with the technology involved. But even in this stage, before a firm may know enough to have a useful first meeting with NASA, the Agency has resources which can be useful in identifying appropriate concepts. NASA seminars, studies, and publications can be excellent sources of information on the state of research in a particular field, and under the new Commercial Space Policy, seed-funding is expected to be made available for the investigation of new concepts. Also, a NASA-supported intermediary can help a company or individual identify concepts which would be directly applicable to a firm's technology. And by virtue of having assisted numerous companies in their dealings with NASA, that same intermediary can simplify a company's approach to NASA and protect its proprietary interests at the same time.

## FEASIBILITY ASSESSMENT

### Existing Enterprise – Space-based Production

The initial discussions between a company and NASA will provide additional technical information which the company will want to factor into its technical feasibility assessment. This information may relate to prior NASA or NASA-funded research related to the mission concept, but it will also include data on the Space Shuttle and any existing pieces of space fixtures, instrumentation or other hardware which may be useful to the company in the development of its concept. Further information on available space services can be obtained at this stage from private sector suppliers of these services.

In addition to technical information, NASA will be able to provide more detailed information on its available incentives and cooperative programs to support commercial space research, as well as information on the cost of the space services which might be required to support space-based production. Here, again, private sector suppliers of these services can be considered. With these inputs, the company can conduct a more detailed economic feasibility analysis, including an assessment of the level of investment in development which might be necessary and the ongoing cost to support space-based production. This analysis must also consider the size of the market(s) for the new product or service and the price at which such a new or improved product would have to sell to produce a fair return on the investment.

From the technical and economic feasibility analyses the company should have enough of an understanding of its concept to propose some form of cooperative agreement with NASA. Often the first step in the agreement process is to develop a Memorandum of Understanding between the company and the Agency. This document usually states that the company has an interest in exploring a particular concept, that NASA is willing to offer its assistance in that effort, and that the two sides will attempt to develop a joint agreement during the time in which the MOU is in effect. This document is useful to both sides in that it expresses the commitment of the other side to developing an agreement, but carries no other commitment beyond their intention to negotiate.

With or without an MOU, the negotiation of a joint agreement with NASA will require that the company have enough of an understanding of the development process for its concept to determine what type of assistance it would require from NASA. This would probably include the number of flights that might be necessary, the time necessary between flights to evaluate results and prepare for the next flight, the type of apparatus to be flown and the Shuttle accommodations it would require, and the type and level of technical assistance that might be required from NASA to support the company's development efforts. With this type of information a company can develop and enter into a joint agreement with NASA.

### Entrepreneurial Ventures

For entrepreneurial ventures, feasibility assessment follows basically the same path, but takes on a much more critical flavor, since most or all of the new company's assets may be committed to the project. Thus the firm should also be developing an initial business plan in parallel with the negotiation of its agreement with NASA. Once an agreement is reached, both the agreement and the business plan will be necessary for obtaining capital, which will be the



first step in carrying out the R&D program. While it is certainly possible to obtain some financing before an agreement with NASA is reached, the agreement lends significant credibility to the venture and would enhance its attractiveness in the eyes of potential investors.

### Existing Enterprise – Ground-based Production

The process for assessing the feasibility of a ground-oriented research program closely parallels the space-oriented one, with the exception that the more expensive and complex space production is not contemplated. The company should always be alert to the possibility that its research may determine that space-based production offers a significant economic advantage over an improved ground process, and hence should keep open its options to pursue space-based production at some time in the future.

### Summary – Feasibility Assessment

The accurate assessment of a concept's technical and economic feasibility is essential both to the continued development of the concept and to the negotiation of a joint agreement with NASA. It is crucial to an entrepreneurial venture because the resulting business plan will be the basis for soliciting capital.

As in the concept development phase, NASA has resources available which can assist the company in carrying out a feasibility assessment and negotiating a joint agreement. A NASA-supported intermediary can assist the company in finding the necessary technical and economic information, both inside NASA and elsewhere. It can also guide the company through its negotiations with the Agency, using its understanding of previous agreements, the quid pro quos which NASA may be obliged to seek, and in particular the NASA organization and the negotiation process itself.

In addition, NASA's new Commercial Space Policy includes a number of incentives designed to lower the cost of developing a space venture, and these will help make both the technical and economic aspects of new ventures more attractive. These incentives include:

- o Grants for commercially-oriented research
- o Access to NASA expertise and patents
- o Free and reduced-rate space flights through agreements such as the JEA
- o Use of NASA ground facilities, including cooperation through technical exchange agreements (TEA's)
- o Fewer safety and regulatory restrictions on payloads
- o More rapid payload integration and processing
- o Possible NASA purchase of commercial space products and services

- o Dedicated commercial payload opportunities or “stand-by” payload status
- o Potential tax, financial, and insurance incentives, subject to legislative action.

Many of these incentives will prove useful to both existing enterprises and entrepreneurial ventures as they develop and assess the feasibility of their concepts. While NASA will not normally agree to long term exclusive sourcing, the probability of government use of the firm’s product or service can be a positive factor in the economic analysis, and should be developed in discussions parallel to those leading to joint agreements.

## R&D PROGRAM

### Existing Enterprise – Space-based Production

Once a joint agreement has been negotiated with NASA, the company can prepare a detailed R&D program taking advantage of the NASA capabilities provided through the agreement. Concurrently with development of this R&D program, an equally thorough time-phased business plan should be prepared, based again on the NASA assistance which will be provided through the agreement. The NASA input includes technical assistance and the schedule on which it will be provided. The economic aspects of NASA’s support are a function of whatever incentives have been included in the agreement.

The R&D program is then executed, using the flights, ground facilities, and other incentives provided under the agreement. Based on the results of the R&D program, the company can update its economic analysis of the venture and prepare to move on to the development of a production prototype.

### Entrepreneurial Ventures

For an entrepreneurial venture, additional funds must often be obtained before it can afford to carry out the R&D program. Thus, in parallel with the development of the detailed R&D program, the company must obtain adequate financing to cover at least the demonstration portion of its R&D program. This is not to say that a new venture should necessarily wait until it has an agreement with NASA to begin seeking venture capital, only that in order to proceed into the R&D program sufficient capital must be available. Often capital can only be obtained on the combined strength of the business plan, the R&D plan, and the terms of the joint agreement with NASA. The R&D program thus becomes the “proof of concept” supported by an initial increment of funding. A successful R&D program would then be necessary before any additional funds could be solicited. The entrepreneurial firm may want to consider offering a stake in the venture to potential contractors as an alternative to a conventional venture capital solicitation.

Once the R&D program is underway and some results are available, the entrepreneurial firm can begin to update its business plan in preparation for seeking any additional financing which may be necessary to support development of a production prototype. The update to the business plan from the R&D program will include both more accurate technical information on the qualities of the product or service, and a more definitive set of costs for the economic portion of the plan.

## Existing Enterprise – Ground-based Production

The R&D program for a company exploring improvements to its ground-based production process will be somewhat different than the R&D program for space-based production. The business plan for the space-based process is replaced for the ground-based case by a process improvement plan – a time-phased plan for incorporating the knowledge gained in space into the company's ground-based operations.

Once the R&D program is underway, several iterations of assessing results and modifying subsequent experiments will probably be necessary to produce the desired results. Once satisfactory results have been obtained, the economic aspects of those results can be input to the process improvement plan, and the company can proceed to the next phase.

### Summary – R&D Program

For each of the three scenarios, the R&D programs design should allow for several experimental runs. The duration of this experimental loop should be controlled by both technical (“Can further useful data be acquired?”) and business (“Do the potential benefits of further experiments outweigh the costs?”) considerations. Planning too short an R&D program or terminating it too soon can be as big a mistake as pursuing poor results for too long. On the other hand, the potential value of very low cost “blind stabs” (e.g. Getaway Specials) should not be overlooked, since to date very little experimental work has been done in a number of fields, and the chance for serendipitous discoveries may be too good to pass up.

In all three scenarios it is essential that technical and business developments be carried out concurrently. Neither can afford to get very far ahead of the other, and in many cases conditions may be such that one cannot proceed unless the other is being properly executed.

Companies should also be sure to take advantage of as many of NASA's capabilities as possible in the R&D phase. In particular, NASA technical literature, facilities, and personnel should be used wherever necessary to simplify the execution of the program and reduce its cost. In particular, the commitment in NASA's Commercial Space Policy to shorten the time necessary to integrate and fly commercial experiments and payloads, combined with the increasing frequency of shuttle flights, should make the time needed to carry out the R&D program much more suitable for companies concerned with a return on their investment.

In the next few years, the only readily available means of carrying out R&D programs in space will be the Space Shuttle, using either the mid-deck of the crew module, the payload bay, or possibly the Spacelab. At some point free-flying spacecraft such as Fairchild's Leasecraft, MBB's SPAS, or ESA's Eureka may be available, but unless they are somehow accessible through an agreement with NASA, they may not be economical for R&D purposes. In the early 1990's, the proposed Commercial Space Station Laboratory, with its ability to conduct experiments unconstrained by shuttle flight durations, should become an attractive alternative for carrying out commercial R&D.

## PROTOTYPE DEVELOPMENT

### Existing Enterprise – Space-based Production

The results of the R&D program are used to design, build, and fly a prototype production unit. Concurrent with construction and flight of the prototype, the firm must begin to execute its business plan, including the development of the initial product plan encompassing marketing, pricing, production, and distribution.

### Entrepreneurial Venture

For the entrepreneurial firm, construction of a prototype may require the influx of additional capital, preparation for which should start during the R&D program once some results are available. This may require taking on new venture partners in exchange for their financial or operational contributions to the venture.

### Summary – Prototype Development

Under the terms of NASA's Commercial Space Policy, the level of the Agency's support to a venture may begin to decline as it approaches operations. While it may be possible to include flights for the prototype in the joint agreement, it might be wise to anticipate that they may well begin to have more significant costs associated with them.

## PRODUCTION/INCORPORATION INTO GROUND-BASED PRODUCTION

In this phase, the design of the production unit is finalized from the results of prototype testing, the unit is built, the product plan is completed, and production is implemented.

In the ground-based production scenario, the results of the R&D program are applied to the ground-based process, the improved process is put into production, and modified product pricing and marketing are initiated.

For either of the space-based production scenarios, a particular location will have been chosen at which to carry out the production operation. In the late 1980s the available locations will probably only consist of shuttle flights of up to several weeks in length (if man-tending is required), or unmanned free-flying platforms such as Leasecraft, SPAS, or Eureka for durations of up to several months before maintenance or resupply is necessary. In the early 1990s, the space station should be available to handle a limited number of commercial production operations beyond those already foreseen for it (i.e., McDonnell Douglas/Johnson and Johnson electrophoresis units, and Microgravity Research Associates crystal growth units). While some provisions are being made to accommodate a few other production operations on the initial capability space station, the chance that additional space station facilities will be needed by the mid-1990s may turn out to be quite high.

## CONCLUSION

President Reagan's commitment in January 1984 to construction of a permanent manned space station and to government support of commercial space ventures has made private sector companies and individuals much more aware of the opportunities that the space environment holds for them. If they are to successfully undertake such ventures, they must do so in the same methodical fashion in which they would approach any other new venture.

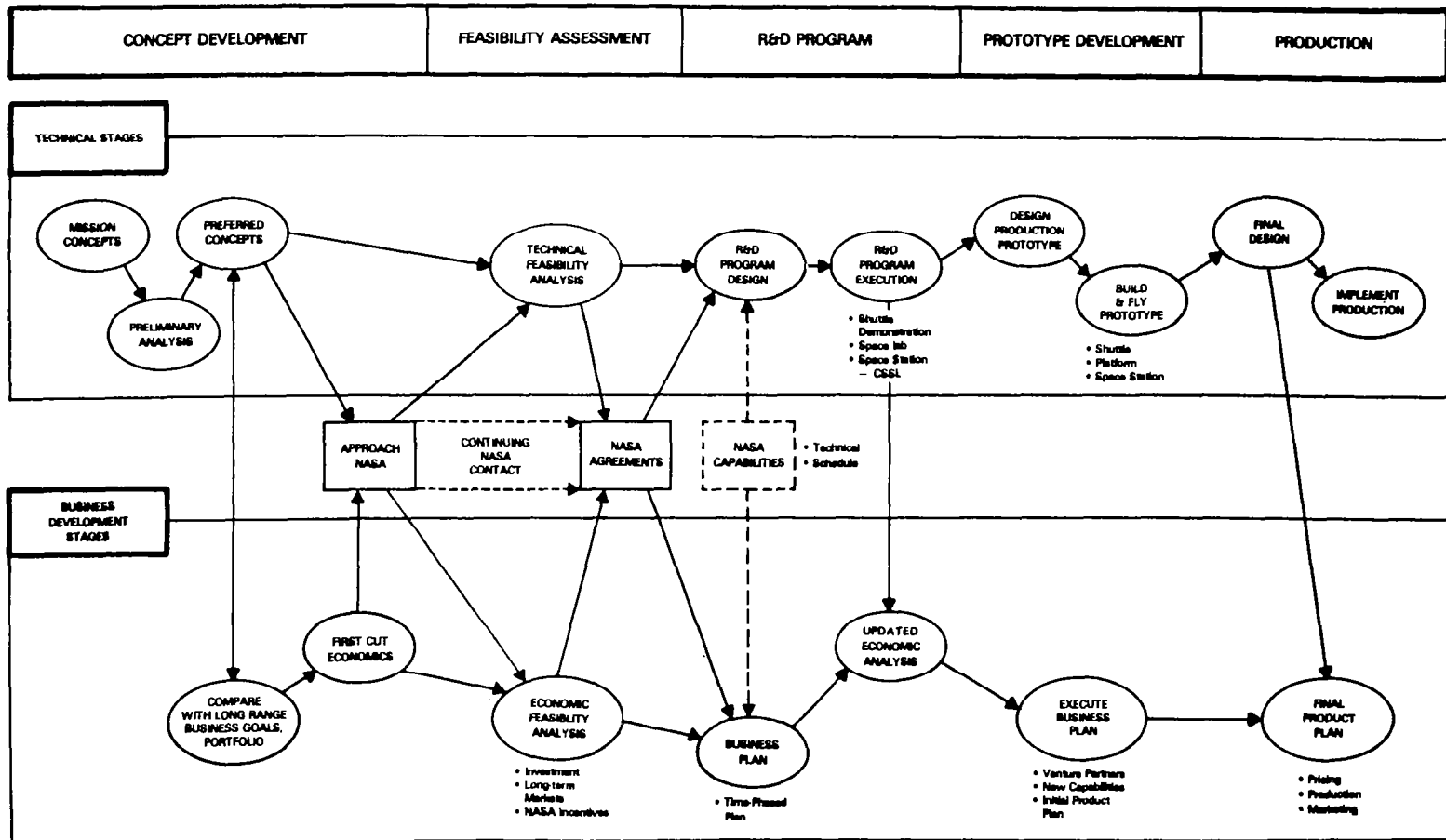
This paper has presented a step-by-step process through which an existing enterprise or an entrepreneurial venture can initiate and carry out a new space venture. It should be emphasized that throughout this process the business and technical aspects must be advanced in parallel with each other. Each depends on the other for its continued success, and companies may be unable to complete the venture if one or the other has been neglected.

While conceiving and developing a space venture has been difficult in the past, NASA's existing programs and the experience of early trailblazers provide sufficient examples and opportunities for other firms to undertake new ventures with confidence. With the introduction of NASA's new Commercial Space Policy, both the opportunities and the ease with which ventures can be carried out should increase significantly. Private sector firms should act quickly to take advantage of these opportunities created by the President's new emphasis on commercial space activities.

Booz, Allen and Hamilton is presently under contract to NASA's Space Station and Commercialization Task Forces to assist users in the development of their concepts for space ventures, and to aid NASA in developing appropriate policies, programs, and incentives for the support of private sector activities in space.

# COMMERCIAL MISSION DEVELOPMENT

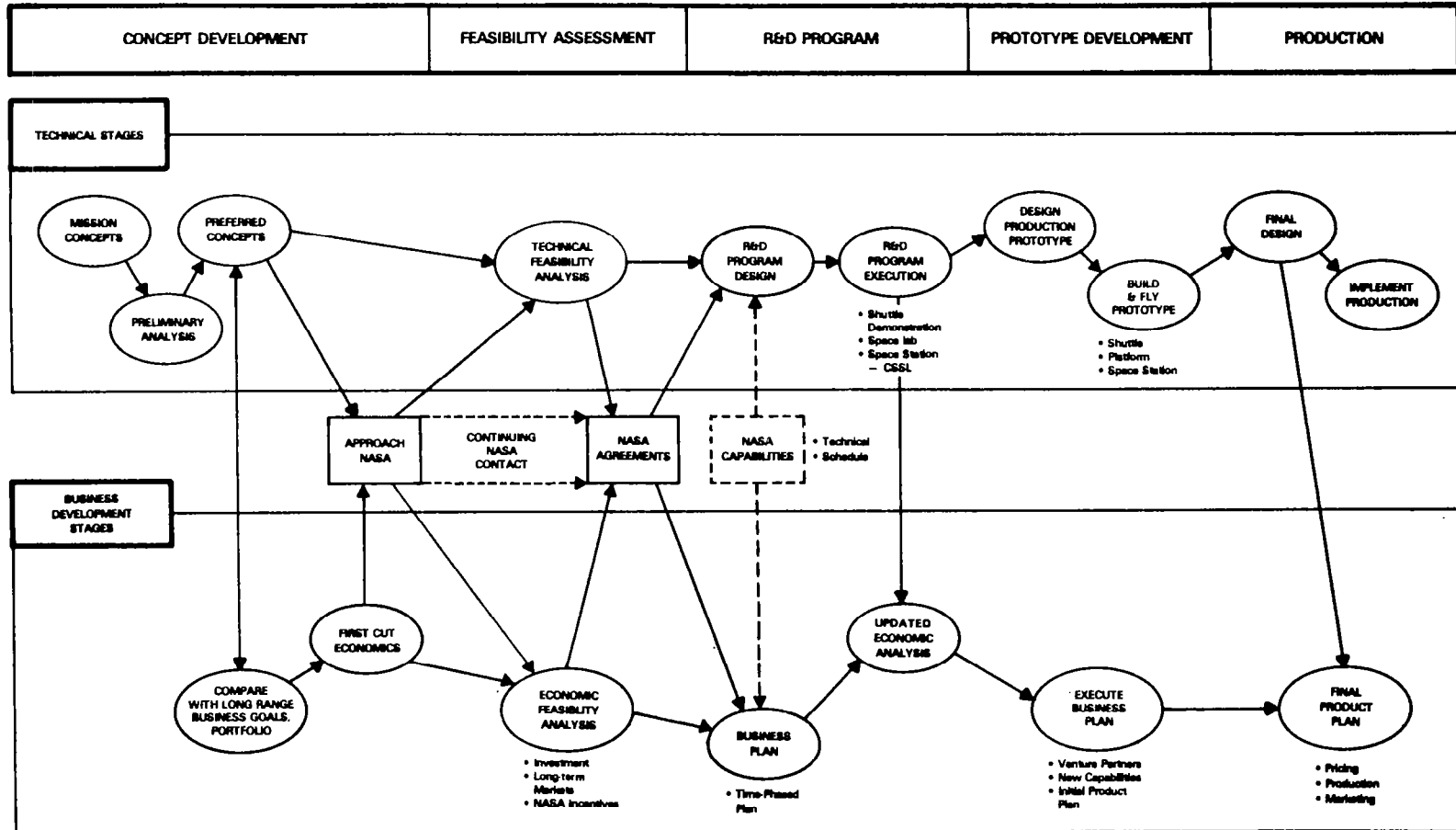
## EXHIBIT I. EXISTING ENTERPRISE – SPACE-BASED PRODUCTION



BOOZ ALLEN & HAMILTON INC.

# COMMERCIAL MISSION DEVELOPMENT

## EXHIBIT I. EXISTING ENTERPRISE – SPACE-BASED PRODUCTION



Excerpt from:  
State of the Union Address  
by  
President Ronald Reagan  
January 25, 1984

Our second great goal is to build on America's pioneer spirit and develop our next frontier. A sparkling economy spurs initiative and ingenuity to create sunrise industries and make old ones more competitive.

Nowhere is this more important than our next frontier: space. Nowhere do we so effectively demonstrate our technological leadership and ability to make life better on Earth.

The space age is barely a quarter of a century old, but already we've pushed civilization forward with our advances in science and technology. Opportunities and jobs will multiply as we cross new thresholds of knowledge and reach deeper into the unknown.

Our progress in space, taking giant steps for all mankind, is a tribute to American teamwork and excellence. Our finest minds in government, industry, and academia have all pulled together, and we can be proud to say: we are first, we are the best, and we are so because we are free.

America has always been greatest when we dared to be great. We can reach for greatness again.

We can follow our dreams to distant stars, living and working in space for peaceful, economic and scientific gain. Tonight, I am directing NASA to develop a permanently manned space station and to do it within a decade.

A space station will permit quantum leaps in our research in science, communications and in metals and life-saving medicines which can be manufactured only in space.

We want our friends to help us meet these challenges and share in their benefits.

NASA will invite other countries to participate so we can strengthen peace, build prosperity and expand freedom for all who share our goals.

Just as the oceans opened up a new world for clipper ships and Yankee traders, space holds enormous potential for commerce today.

The market for space transportation could surpass our capacity to develop it. Companies interested in putting payloads into space must have ready access to private sector launch services.

The Department of Transportation will help an expendable launch services industry to get off the ground. We will soon implement a number of executive initiatives, develop proposals to ease regulatory constraints, and, with NASA's help, promote private sector investment in space.



# MISSION MODES FOR A RETURN TO THE MOON

by

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and

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## ABSTRACT

A number of discussions have been reported recently concerning a return to the Moon by the United States. Most of these have been in the context of a permanent presence, i.e., a base.

This paper describes several potential mission modes and transportation options for manned lunar missions in the modern context of the present space transportation system as the basic building block. Transportation options include shuttle and shuttle-derived launch systems and upper stages based on OTV-class vehicles defined by recent studies performed for NASA.

Benefits of staging options, aerobraking, and use of lunar-derived oxygen are quantified. Logical evolution alternatives are presented beginning with no dependence on lunar resources, evolving to more efficient modes later using the same basic transportation elements but capitalizing on the performance benefits available from lunar oxygen. Cost sensitivities are described and it is shown that the transportation technology now available can make a return to the Moon affordable.

Preliminary aggregated transportation requirements for base buildup, activation, and resupply are presented, based on lunar base definition studies conducted by NASA about a decade ago.

Technology and development commonality with the proposed NASA space station are discussed, and rough-order-of-magnitude cost comparisons are presented. It is concluded that the affordability of a return to the Moon should not be judged in the context of Apollo runout costs expressed in current dollars. Contemporary technology permits contemplation of creating a permanent presence on the Moon for roughly one-fifth of the current dollar cost of Apollo.

## THE APOLLO LEGACY – FOOTPRINTS ON THE MOON

Twenty-three years ago this May, the United States was launched on a dramatic course to the Moon by President John F. Kennedy. The events of Apollo are now historical enough that the enormity of the task as viewed from 1961 is often forgotten.

No American had flown in space longer than five minutes. Only the sketchiest of preliminary designs for the vehicles existed. The mission mode had not been chosen and the one selected about a year later was not even recognized as a candidate. The Saturn Moon rocket would be twenty times larger than the Atlas, the largest rocket that had been built in the U.S. up to that time. Conditions on the lunar surface were virtually unknown and the feasibility of landing was uncertain.

And yet in just over eight years, all these difficulties were surmounted and Neil Armstrong stepped down on the surface of another world.

## OBJECTIVES OF THIS PAPER

The United States left the Moon over eleven years ago. No one else has visited since. Recently, discussion of a return to the Moon has been offered from various sources. It seems timely to investigate the application of contemporary vehicles and technology to a return to the Moon (Fig. 1).

## WHY RETURN?

There are several reasons for a return (Fig. 2). The Moon is another planet, very different from Earth. We are still scientifically exploring our own world, and the research opportunities on the Moon are virtually unlimited.

Many concepts have been proposed for utilizing the indigenous resources on the Moon; the creation of an extraterrestrial human colony, if affordable, would be a step of unprecedented historical significance.

## SCIENTIFIC PAYOFF

The scientific payoff of the Apollo missions was not immediately evident; scientific payoff takes a long time to develop (Fig. 3).

We now know that the scientific return from Apollo completely revolutionized our concepts of planetary and solar system evolution; it is now impacting our perceptions of Earth's history and structure.

## THE INEVITABLE OBJECTION

Apollo, of course, was very expensive – 24 billions in about 1967 dollars. The inflation factor from 1967 to 1984 is almost exactly 3.

There is, of course, new technology that can be brought to bear. What this does to costs is the key question (Fig. 4).

# Objectives of this Paper

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- **To understand the requirements for establishing a permanent human presence on the moon with 1980's technology.**
- **To understand the interrelationships between a lunar base and a space station.**
- **To develop rough-order-of-magnitude costs for a return to the moon.**

Figure 1

## Why Return ?

---

- **Scientific**
  - **Unanswered lunar science questions**
  - **Research which utilizes lunar environmental characteristics**
- **Exploitation of lunar resources**
  - **Liquid oxygen**
  - **Metals for structural application**
- **First extraterrestrial human colony**
  - **Self-sufficient capability**
  - **International**

Figure 2

## Scientific Payoff

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**“The contrast with the pre-Apollo understanding of lunar composition is complete. No model survived the encounter with the Apollo sample data.”**

**“The nine suites of samples recovered by the Apollo and Luna missions have provided so many answers that it is now difficult to recall our state of ignorance before July 1969.”**

**Stuart Ross Taylor**  
**Planetary Science – A Lunar Perspective**

Figure 3

## The Inevitable Objection

---

**“Going back to the moon would cost  
100 BILLION DOLLARS!”**

**Would it, now?**

**The way people arrive at that figure is to multiply the Apollo runout cost of \$24 billion by an inflation factor of 3 and then round up to an even figure.**

**But this is 1984, not 1961.**

Figure 4

## PARAMETERS OF PERMANENT PRESENCE ON THE MOON

Most discussions of a return to the Moon are in a context of permanent presence. There were several studies of lunar bases in the 1965-1975 time period. The parameters of permanent presence were derived from the results of those studies (Fig. 5).

### BASE EQUIPMENT DELIVERY REQUIREMENTS

These delivery requirements were derived from a Rockwell study of a lunar base circa 1971, and modified to reflect current space station habitability concepts and emphasis on development of lunar resources (Fig. 6).

### BASE RESUPPLY SUMMARY

Base resupply requirements were also derived from the earlier works. The resupply interval was shortened to reduce the payloads to within the capability range of vehicle concepts to be presented on Figure 7.

### LUNAR MISSION GROUND RULES

These ground rules were established to realize cost benefits from space shuttle as well as emerging advanced cryogenic upper stage technology (Fig. 8).

### EARLY MODES

The mission modes used for base buildup and activation clearly cannot be dependent on lunar oxygen (Fig. 9).

### LUNAR MISSION MODES COMPARISON

Of the many possible lunar mission modes, four were selected for analysis in this paper (Fig. 10). These modes lend themselves to satisfying the ground rules laid down on an earlier chart. Note the symbolism on the upper left panel for landing legs and aerobrake kits added to the basic stages.

Where crew transfers occur, a crew cab is provided on each vehicle. Crew cabs are not transferred, although this would provide better mission performance. It was felt that crew cab transfer raises vehicle integration issues.

The flight profiles are sketched here, not to scale, of course (Fig. 11). To minimize clutter in the figure, the elliptic booster orbit and aeropass are each shown only one place, rather than for every use. Refer to the prior chart for description of where these mission elements are used. The booster parking orbit varies with mission mode and payload, but is typically a six-hour elliptic orbit.

# Parameters of Permanent Presence on the Moon

- 12-person base using space-station-derived habitation and lab modules.
- Scientific equipment for planetology and astrophysics.
- Mobility systems for extended exploration and sample acquisition traverses.
- Prototype equipment for lunar resources utilization, initially concentrating on propellant oxygen production.
- Construction and handling equipment necessary to establish and activate the base.

Figure 5

## Base Equipment Delivery Requirements

---

- Flights 1 and 2 – Habitat modules
  - Flights 3 and 4 – Laboratory/work modules
  - Flight 5 – Construction equipment
  - Flight 6 – Nuclear power plant (100 KWe)
  - Flight 7 – Solar/regen fuel cell emergency power supply
  - Flight 8 – Scientific equipment
  - Flight 9 – Mobile explorer
  - Flight 10 – Lunar oxygen production plant
- Each flight has cargo capacity 13 tonnes (28,500 pounds)

Figure 6

# Base Resupply Summary

---

- Crew staytime 180 days
- Exchange interval 4 crew/60 days
- Resupply (per 60 days):
  - Food, water and atmosphere 3.30 tonnes
  - EVA 0.27 tonnes
  - Science 0.22 tonnes
  - Equipment and subsystems 1.21 tonnes
  - 5.00 tonnes (11,000 pounds)
- Crew transport module (4 people) – 5.0 tonnes
- Net delivered – 10
- Net returned – 5

Figure 7

## Lunar Mission Mode Ground Rules

---

- All employ shuttle or shuttle-derived launch vehicles
- At least one mode with capability to deliver more than 10 tonnes per flight to lunar surface
- O<sub>2</sub>-H<sub>2</sub> space propulsion
- Upper stages in OTV size class for commonality with other uses of advanced cryogenic upper stage
- Base buildup and activation modes not dependent on lunar resources
- Conservative mass and performance characteristics
- Aeroassisted return to low earth orbit; lunar oxygen phased in for base resupply operations
- All modes insensitive to performance variations

Figure 8

# Early Modes

---

- **Base buildup cargo modes can leave the lander on the moon**
  - **Spent stages serve as propellant tank farm**
  - **Spent stages can be cannibalized for spare parts**
  - **Stages not worth the cost to return**
- **Base activation needs an “independent” mode**
  - **Not dependent on lunar base**
  - **Not dependent on lunar oxygen**

Figure 9



# Lunar Mission Modes Comparison

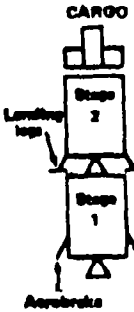



<p><b>LSS-1008 DIRECT CARGO</b></p>  <ul style="list-style-type: none"> <li>• BOOST TO TRANSLUNAR INJECTION (TLI)</li> <li>• RETROFIRE TO LUNAR ORBIT &amp; SURFACE LANDING</li> <li>• STAGE 2 REMAINS ON LUNAR SURFACE</li> <li>• BOOST TO ELLIPTIC ORBIT</li> <li>• SEPARATE</li> <li>• AEROASSISTED RETURN TO LEO</li> </ul>	<p><b>SORTIE</b></p>  <ul style="list-style-type: none"> <li>• LUNAR DESCENT FROM LO</li> <li>• LUNAR ASCENT TO LO</li> <li>• JETTISONED IN LO</li> <li>• BOOST TO TLI</li> <li>• RETROFIRE TO LO</li> <li>• WAIT</li> <li>• RETURN TO LEO (AERO-ASSISTED)</li> <li>• BOOST TO ELLIPTIC ORBIT</li> <li>• SEPARATE</li> <li>• AEROASSISTED RETURN TO LEO</li> </ul>	<p><b>SURFACE REFUEL</b></p>  <ul style="list-style-type: none"> <li>• BOOST TO TLI</li> <li>• RETROFIRE TO LO &amp; LS</li> <li>• DISCHARGE CARGO</li> <li>• TAKE ON OXYGEN</li> <li>• RETURN TO EARTH ORBIT VIA LO</li> <li>• BOOST TO ELLIPTIC ORBIT</li> <li>• SEPARATE</li> <li>• AEROASSISTED RETURN TO LEO</li> </ul>	<p><b>LUNAR STATION (LUNAR ORBIT, HALO ORBIT, OR SWING ORBIT)</b></p>  <ul style="list-style-type: none"> <li>• TRANSFER CREW, TAKE ON CARGO</li> <li>• TAKE ON HYDROGEN</li> <li>• DESCEND &amp; LAND</li> <li>• OFFLOAD CARGO</li> <li>• TAKE ON OXYGEN</li> <li>• ASCENT TO LO &amp; RENDEZVOUS</li> <li>• BOOST TO TLI</li> <li>• RETRO TO LO</li> <li>• RENDEZVOUS WITH STATION</li> <li>• TRANSFER CREW, CARGO</li> <li>• TAKE ON OXYGEN</li> <li>• RETURN TO LEO</li> </ul>
<p><b>ADVANTAGES</b></p> <ul style="list-style-type: none"> <li>• 13-TONNE PAYLOAD</li> <li>• STAGE 2 SERVES AS TANK FARM ON LUNAR SURFACE</li> </ul> <p><b>DISADVANTAGES</b></p> <ul style="list-style-type: none"> <li>• STAGE EXPENDED</li> <li>• REQUIRES AUTOLAND</li> </ul>	<p><b>ADVANTAGES</b></p> <ul style="list-style-type: none"> <li>• CREW MODE</li> </ul> <p><b>DISADVANTAGES</b></p> <ul style="list-style-type: none"> <li>• STAGE EXPENDED</li> <li>• CREW CAB EXPENDED</li> <li>• LUNAR ORBIT OPERATIONS</li> </ul>	<p><b>ADVANTAGES</b></p> <ul style="list-style-type: none"> <li>• CREW + CARGO</li> <li>• ALL REUSED</li> <li>• UNCONSTRAINED FLIGHT MECHANICS</li> </ul> <p><b>DISADVANTAGES</b></p> <ul style="list-style-type: none"> <li>• LESS EFFICIENT</li> <li>• LANDING BEAR &amp; AEROBRAKE INTEGRATED ON SAME STAGE</li> </ul>	<p><b>ADVANTAGES</b></p> <ul style="list-style-type: none"> <li>• EFFICIENT (LO BUT NOT MO OR SO)</li> <li>• CREW &amp; CARGO</li> <li>• ALL REUSED</li> </ul> <p><b>DISADVANTAGES</b></p> <ul style="list-style-type: none"> <li>• LUNAR STATION: ADDED FLIGHT MECHANICS CONSTRAINTS</li> <li>• LUNAR ORBIT OPERATIONS</li> <li>• ZERO-<math>\delta</math> PROPELLANT TRANSFER IN LO</li> </ul>
<p>NO LUNAR OXYGEN</p>		<p>LUNAR OXYGEN REQUIRED</p>	

Figure 10

# Mission Modes Comparison

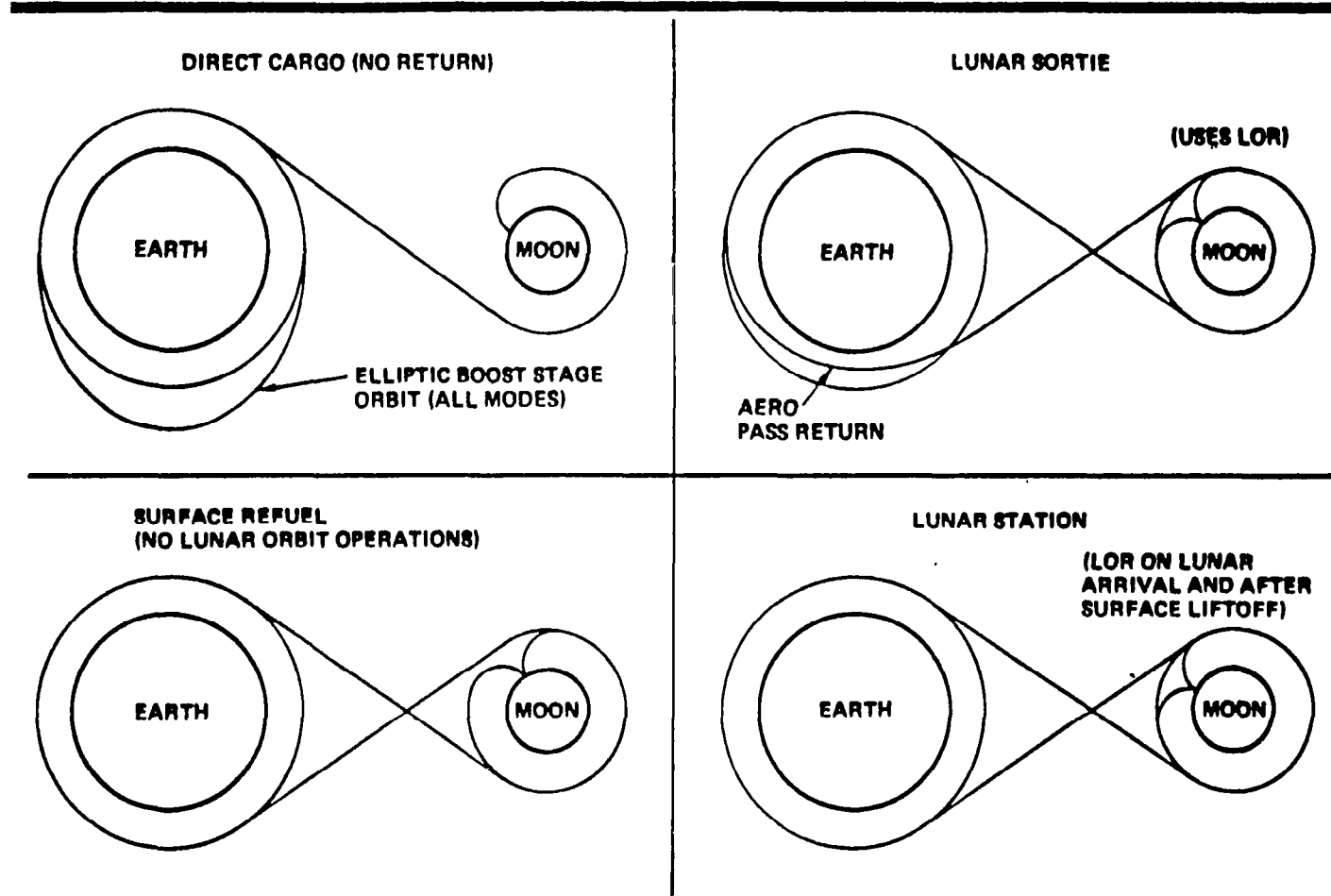


Figure 11

## INDEPENDENT LUNAR SURFACE SORTIE CONCEPT

A concept of the lunar surface sortie vehicle on the lunar surface, from an earlier study, is depicted here (Fig. 12).

## LUNAR LANDER CONCEPTS ARE RELATED TO OTV CONCEPTS

Illustrated here (Fig. 13) is an OTV concept from the Boeing Phase A OTV study for MSFC, and several lunar lander concepts from an earlier space transportation study. OTV definition activities are continuing. In view of the similarity of these vehicle concepts, the lunar transport and lander vehicles will undoubtedly be derived from an OTV.

## SHUTTLE-DERIVED CARGO LAUNCH VEHICLE

As will be seen, the cost advantages of a heavy-lift vehicle such as the one depicted for propellant delivery to Earth orbit are significant (Fig. 14).

## DELTA Vs in KM/SEC

Delta Vs for the mission modes were taken from earlier studies and from Apollo experience (Fig. 15).

## PERFORMANCE AND MASS SUMMARY

Performance and upper stage inert mass calculations for the various mission modes were carried out using iterative algorithms on a personal computer. Results are summarized here (Fig. 16). Numbers in parentheses after stage names are inert mass in metric tonnes. Immediately below are impulse propellant loadings. Added masses for landing legs and aerobrakes are symbolized by LL and AB.

## LOGISTICS TRANSPORT COST SUMMARY, PER MISSION

A summary cost comparison is presented here (Figs. 17 and 18). ROM costs were used; no detailed estimates were made. No amortization of R&D was included; these are recurring costs. These data are presented in bar-chart form.

The most cost-effective modes would permit resupply of a lunar base for half a billion per year or less in transport costs.

## INFLUENCE OF LEO SPACE STATION ON LUNAR OPERATIONS

A space station offers economies in lunar transportation operations through space-basing of the lunar transport stages and through having a vehicle assembly and launch crew available, thus not requiring a shuttle flight merely to provide the human presence (Fig. 19).

# Independent Lunar Surface Sortie Concept

LSS-1009

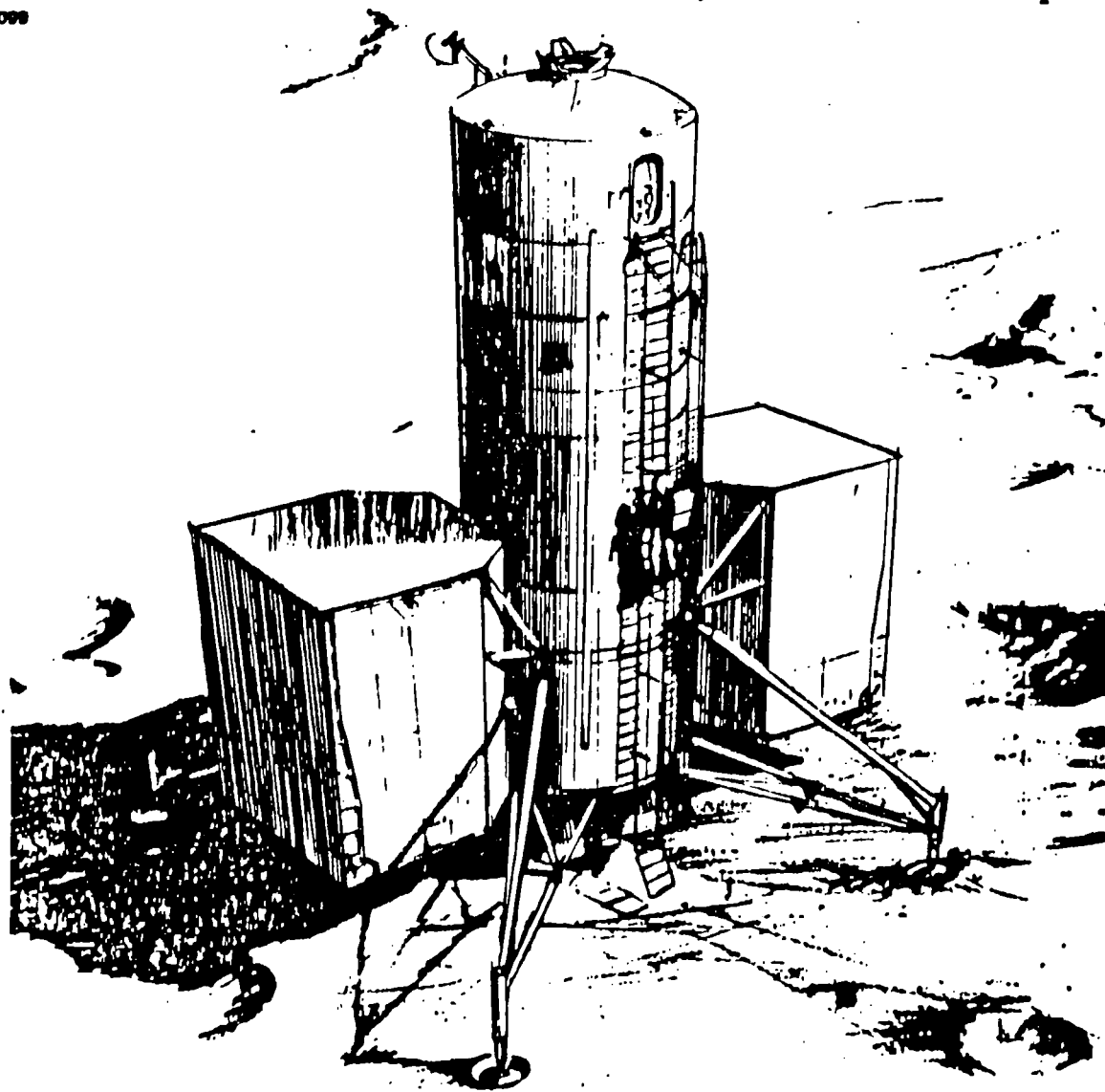


Figure 12

# Lunar Lander Options are Related to OTV Concepts

L88-1100

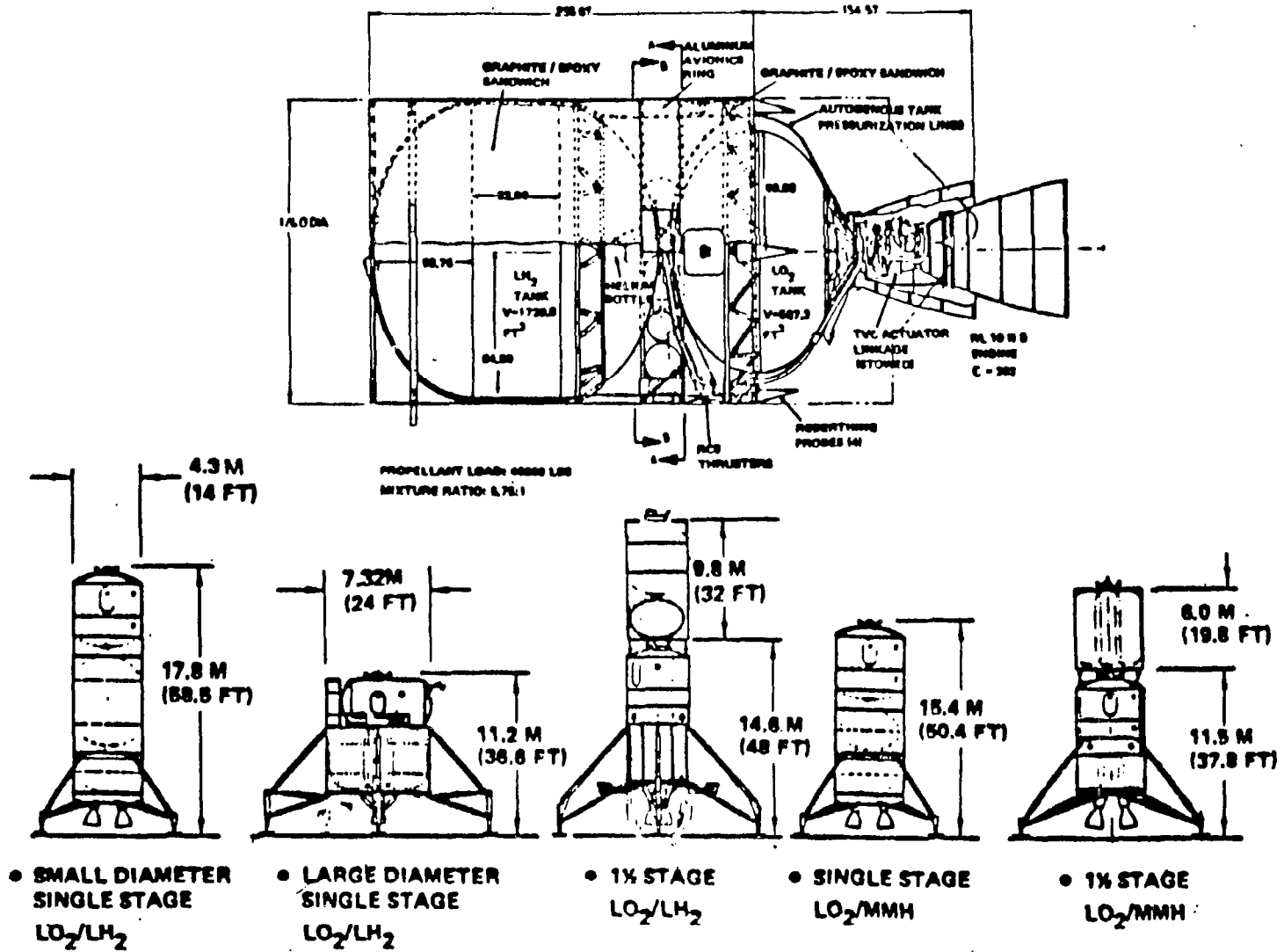


Figure 13

# Shuttle Derived Cargo Launch Vehicle

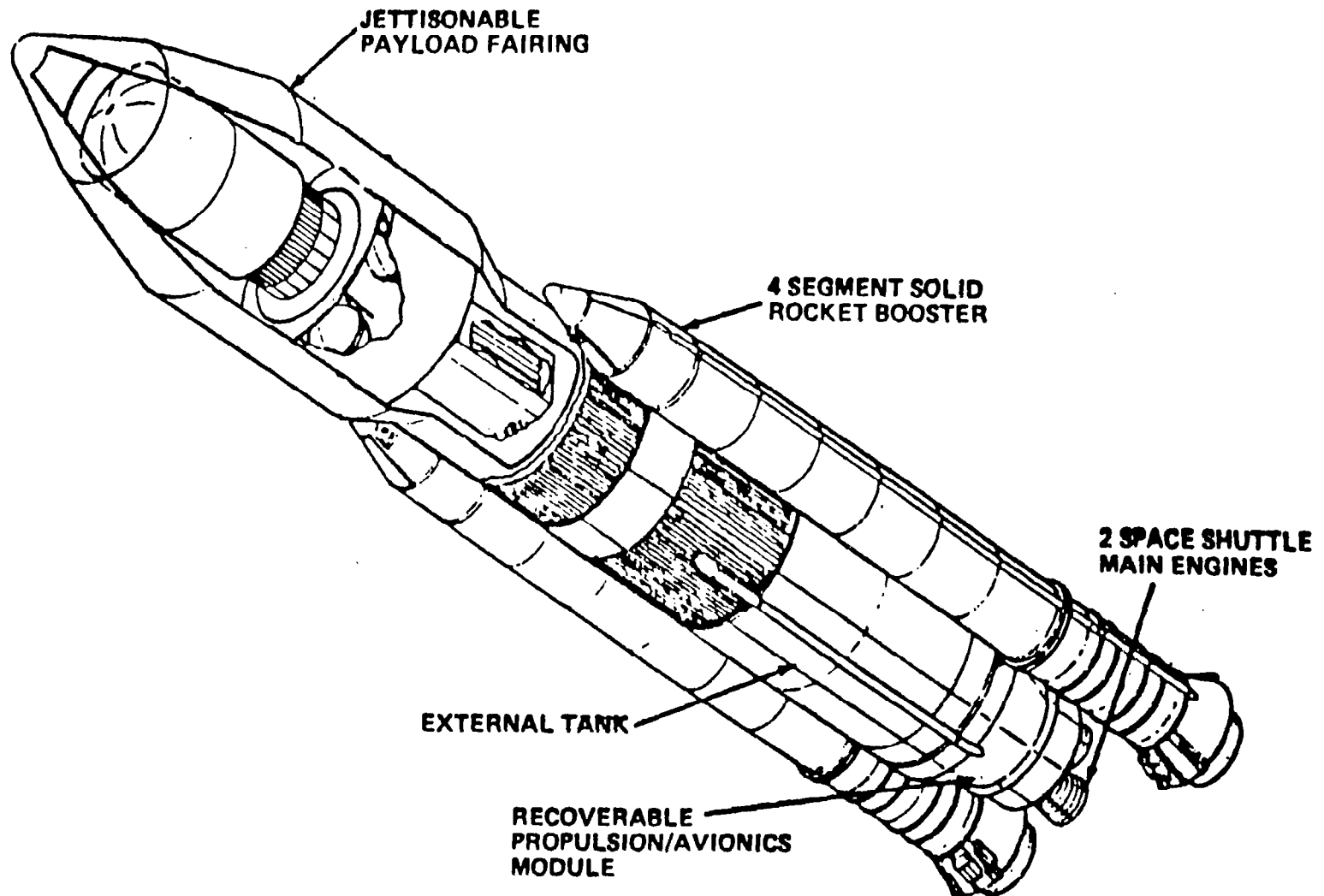


Figure 14

# Delta V's in Km/Sec

---

	<u>(MODES 1-4) 100 KM ORBIT</u>	<u>MODE 5 LUNAR HALO ORBIT</u>	<u>MODE 6 LUNAR SWING ORBIT</u>
<b>TRANSLUNAR INJECTION</b>	<b>3.2</b>	<b>3.2</b>	<b>3.2</b>
<b>LUNAR ORBIT ARRIVAL</b>	<b>0.8</b>	<b>0.4</b>	<b>0.3</b>
<b>DESCENT TO LUNAR SURFACE</b>	<b>2.1</b>	<b>3.0</b>	<b>2.9</b>
<b>ASCENT FROM LUNAR SURFACE</b>	<b>2.0</b>	<b>2.9</b>	<b>2.8</b>
<b>TRANS EARTH INJECTION</b>	<b>0.8</b>	<b>0.4</b>	<b>0.3</b>
<b>AEROASSISTED ARRIVAL IN LOW EARTH ORBIT</b>	<b>0.2</b>	<b>0.2</b>	<b>0.2</b>

Figure 15

# Performance and Mass Summary

LSS-1203

MISSION MODE	STAGE 1 (INTEG) AND PROP LOAD	STAGE 2 & PROP LOAD	STAGE 3 & PROP LOAD	PAYLOAD TO LB	PROPELLANT FROM EARTH	LUNAR OXYGEN	TOTAL -	LEO DEPARTURE MASS
							EARTH LAUNCH (SS/EB)*	
(1) DIRECT CARGO	BOOSTER (3.09) 24 AB = 0.323	LUNAR (3.09) 25 LL = 0.483	NONE	13	50	0	68.8/70	70
(2) SORTIE	BOOSTER (3.09) 26 AB = 0.323	EARTH RET (2.72) 22.4 AB = 0.612	LUNAR (2.03) 11.5 LL = 0.33	CREW +1	58.9	0	72.4/79.3	79.3
(3) SURFACE REFUEL	BOOSTER (2.92) 23.8 AB = 0.305	LUNAR & RET (3.02) 24.4 AB = 0.887 LL = 0.47	NONE	CREW +5	48	7.5	68.8/66.7	66.7
(4) LUNAR STATION	EARTH-LB (3.41) 27.8 AB = 0.98	LB-LB (2.48) 20.0 LL = 0.43	NONE	CREW +5	27.8	17.5	326/42	42
(5) SWING (HALO VERY SIMULATOR) <i>SIMILAR</i>	EARTH-LB (3.68) 29.78 AB = 1.01	LB-LB (4.87) 40.2 LL = 0.562	NONE	CREW +5	29.78	34.8	39.78/44.65	44.65

\* SPACE-BASED/EARTH-BASED



# Logistics Transport Cost Summary, Per Mission (Space-Basing Assumed)

LSS-1092

MISSION MODE	NOTE	EARTH LAUNCH PAYLOAD, TONNES	SHUTTLE FLIGHTS @ 35M (26T)	CLV FLIGHTS @ 75M (60T)	UPPER STAGES		CREW CAB		TOTALS (\$M)	
					EXPEND-ED @ 50M	REUSED @ 5M	EXPEND-ED @ 50M	REUSED @ 5M	SHUTTLE (VS) CLV	
DIRECT CARGO	(1)	66.6	2.56	1.11	1	—	—	—	267.8	133
SORTIE	(2)	72.4	2.78	1.21	1	2	1	1	351.3	205.8
LUNAR STATION	(3)	32.6	1.25	0.54	0	2	0	2	126.2	60.5
SURFACE REFUEL	(4)	58.6	2.26	1	0	1	0	1	201.3	86

**NOTES:**

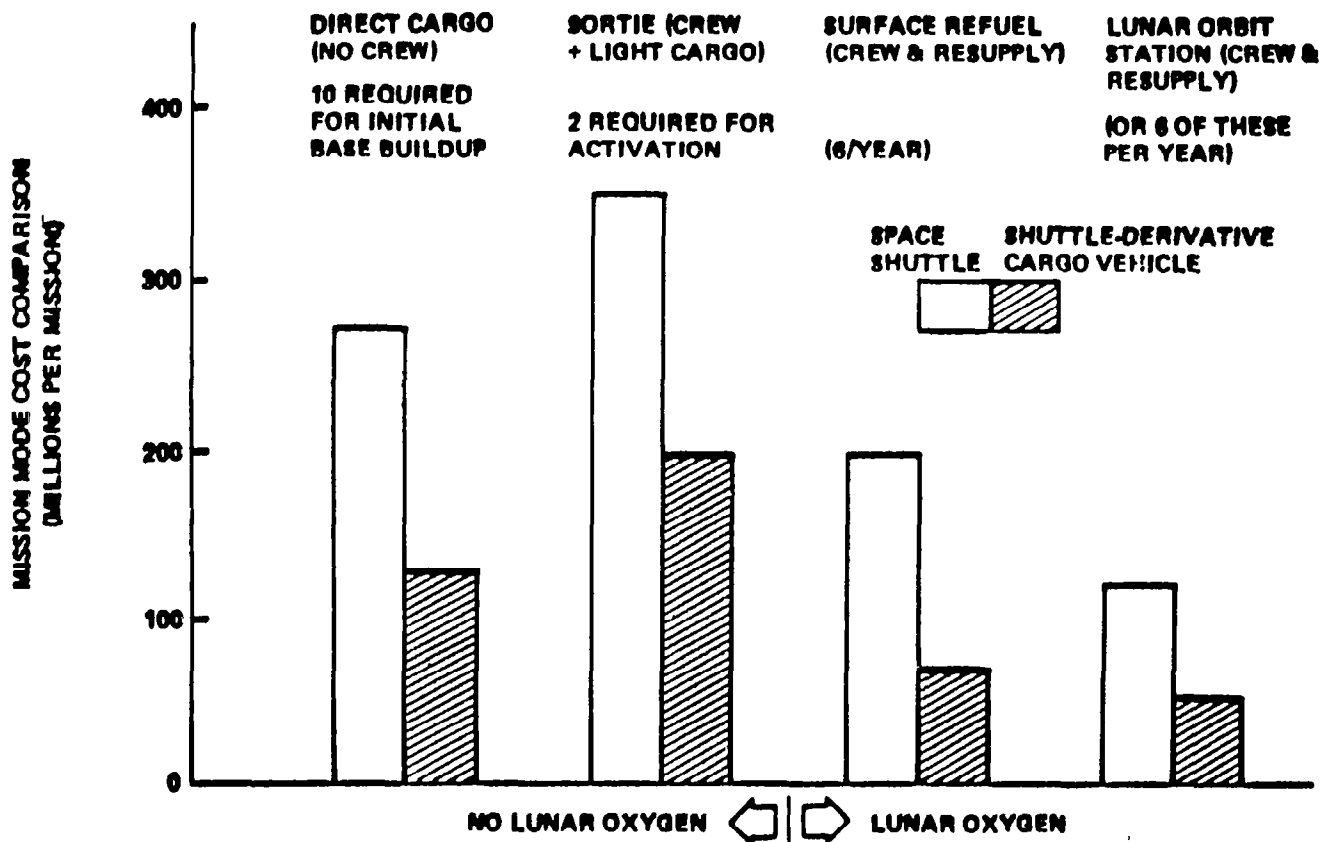
CREW TRANSPORT TO AND FROM LEO NOT INCLUDED

- (1) BASE BUILDUP MODE. COST OF RETURNING DELIVERY STAGE EXCEEDS STAGE VALUE
- (2) ACTIVATION MODE; 14-DAY CREW STAY ON LUNAR SURFACE. DOESN'T USE LUNAR OXYGEN
- (3) RECOMMENDED RESUPPLY MODE. LUNAR STATION CAN BE SIMPLE UNMANNED PLATFORM
- (4) ALTERNATE RESUPPLY MODE; NEEDS LESS LUNAR OXYGEN

Figure 17

# Cost Summary for Lunar Mission Modes, Per Mission (Space Basing Assumed)

L88-1087



**COST ASSUMPTIONS:**

- SHUTTLE - 26 TONNES NET CARGO AT \$95 MILLION
- SDCV - 80 TONNES NET CARGO AT \$75 MILLION
- UPPER STAGE OR CREW CAB EXPENDED - \$50 MILLION
- UPPER STAGE OR CREW CAB OPERATED & REUSED - \$5 MILLION

Figure 18

# Influence of LEO Space Station on Lunar Operations (Costs are Earth Launch Only)

L88-1093

<u>BASE BUILDUP AND ACTIVATION – 10 CARGO FLIGHTS PLUS 2 SORTIES</u>				
	SHUTTLE ONLY	SHUTTLE & SPACE STATION	SHUTTLE + CLV	SHUTTLE + CLV + SPACE STATION
SHUTTLE FLIGHTS	38	33	14	3
CLV FLIGHTS	–	–	14	15
COST (B)	3.2	2.7	2.2	1.4
 <u>BASE RESUPPLY – LUNAR STATION MODE – 6 FLIGHTS PER YEAR</u>				
SHUTTLE FLIGHTS/YR	12	8	6	3
CLV FLIGHTS/YR	–	–	6	3
COST (B)	1	0.7	1	0.5

Figure 19

The feasibility of using a CLV without a space station was not investigated; it was assumed feasible for purposes of comparison. Additional investigation is needed of the uses of a space station to support lunar operations.

## CONCLUSIONS FROM TRANSPORTATION ANALYSIS

The conclusions from the lunar transportation analysis are presented in Figure 20.

## SPACE STATION FUNCTIONS

The main uses of the space station to support lunar operations are listed in Figure 21. These uses were not fully quantified in the comparative analysis presented earlier.

## OPERATIONS, HARDWARE, AND TECHNOLOGY BASE

The commonality between space station and a lunar base are presented on Figure 22. It is seen that most of the operations, hardware, and technology are common. The question of space station versus a lunar base, when asked, must be answered with the commonality in mind, as either option inherently develops most of the capabilities of the other.

## SPACE STATION DIFFERENCES

If a lunar base is contemplated, a few differences in the space station merit consideration, as listed on Figure 23. The habitat issue is mainly one of orientation consistent with use in the lunar gravity environment.

## COMPARATIVE PROGRAM COSTS

The rough, preliminary comparative cost estimate on Figure 24 was made to illustrate the high degree of commonality between a space station and the extension of permanent presence in space to the Moon. Note that the middle column defers certain space station features included in the left hand column, while adding others. This reflects an assumption that if an early lunar base is desired, mission priorities for the space station might be modified.

## EVOLUTION TO LUNAR RESOURCES

Use of lunar oxygen is only the first step in developing lunar resources. The fact that the Moon has indigenous material resources cannot be overemphasized (Fig. 25).

## COST LEVERAGE OF TECHNOLOGY ADVANCEMENTS

If we do return to the Moon, it is not inconceivable that thirty years from now, we would be far enough along in space transportation advancements and use of lunar resources to

## Conclusions from Transportation Analysis

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L88-1114

- **Lunar base buildup and support costs are not a budget-buster. Apollo costs are not relevant to today's technology.**
- **Synergistic cost benefits accrue from:**
  - **Cryogenic (O<sub>2</sub>-H<sub>2</sub>) propulsion**
  - **Aerodynamic-drag-assisted return to low earth orbit**
  - **Lunar production of propellant oxygen**
  - **Shuttle-derived cargo launch vehicle for propellant delivery from earth**
  - **Space station as intermodal transportation node**
- **Preferred mission modes can all use stages in the OTV size class**
- **There is much commonality of hardware and technology with Space Station**
  - **Space Station can be proving ground**
  - **Joint development offers major cost savings and is the least-cost return to the moon program in the long run**
- **There is a logical evolution of lunar mission modes from buildup through activation and support**
  - **Common transportation hardware and technology**
  - **Evolves to use of lunar oxygen after production plant delivered and activated**

Figure 20

# Space Station Functions

---

- Store/base/service – earth lunar stage
- Store/transfer propellant
- Isolate launch operations from space operations
  - Smooth out mismatches
  - No waiting
- House crews in transit
- Assist rendezvous, assembly, etc.
- Proving ground for common technologies

Figure 21

## Operations Hardware and Technology Base

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L88-1111

### Space Station/OTV

### Lunar Base

<u>Unique</u>	<u>Common</u>	<u>Unique</u>
Attitude control	Habitation/ECLS	Throttleable engine
Orbit makeup propulsion	Space-based upper stage	Oxygen production
Zero-g EVA	Power	Surface mobility
	Data and comm.	Lunar landing
	Thermal	
	Structures	
	Propellant refrigeration and storage	(nuclear power?)
	Zero-g propellant transfer	
	Spacesuits	

Figure 22

# Space Station Differences if Lunar Base Contemplated

---

- Habitats designed for alternate use on lunar surface
- Orbit selection – consider lunar access synchronism, e.g., 31.6° at 528 km
- Transportation facility designed to handle CLV tanker and OTV/lunar lander assemblies

Figure 23

## Comparative Program Costs (ROM)

---

	<u>INITIAL SPACE STATION</u>	<u>SPACE STATION + LSB</u>	<u>LUNAR SURFACE BASE (LSB)</u>
DEVELOP PRESSURE MODULE TECHNOLOGY	1.0	1.0	1.0
DEVELOP RESOURCES MODULE TECHNOLOGY	1.0	1.0	0.5
ACQUIRE 2 SPACE STATION HABITAT MODULES	1.0	0.8	–
ACQUIRE SPACE STATION RESOURCES MODULE	1.0	1.0	–
ACQUIRE SPACE STATION RESUPPLY MODULES	0.5	0.5	–
ACQUIRE AND OUTFIT SPACE STATION LABORATORIES	1.0	–	–
DEVELOP LUNAR CRYO STAGE TECHNOLOGY	–	2.0	2.0
DEVELOP AND ACQUIRE SPACE STATION PLATFORMS	1.5	–	–
DEVELOP AND ACQUIRE SPACE STATION HANGAR AND SERVICE FACILITIES	1.0	1.0	0.5
DEVELOP AND ACQUIRE CRYO STAGE SPACE BASING CAPABILITIES	–	1.0	0.5
ACQUIRE AND OUTFIT LUNAR SURFACE LABORATORIES	–	0.5	0.5
ACQUIRE HABITAT MODULES	–	1.0	1.2
ACQUIRE RESOURCES MODULES	–	0.5	0.5
DEVELOP AND ACQUIRE LUNAR OXYGEN CAPABILITY	–	1.0	1.0
DEVELOP SDCV	–	1.0	1.0
BUILDUP LSB	–	1.7	2.7
TOTAL TO IOC	8.0	14.0	11.5
ANNUAL RESUPPLY	0.25	0.5	1.0

Figure 24

# Evolution to Lunar Resources

- Lunar oxygen – high cost leverage – needed early
- Radiation shielding
- Metals for habitat pressure shells and other structure
- Simple components for power systems, e.g., structure, pressure vessels, concentrators
- Food production facility
- More complex hardware with development of powder metallurgy techniques and import of automated flexible manufacturing equipment from earth

Eventual supply from earth may be reducible to less than 1 kg/man-day

Figure 25

## Cost Leverage of Technology Advancements

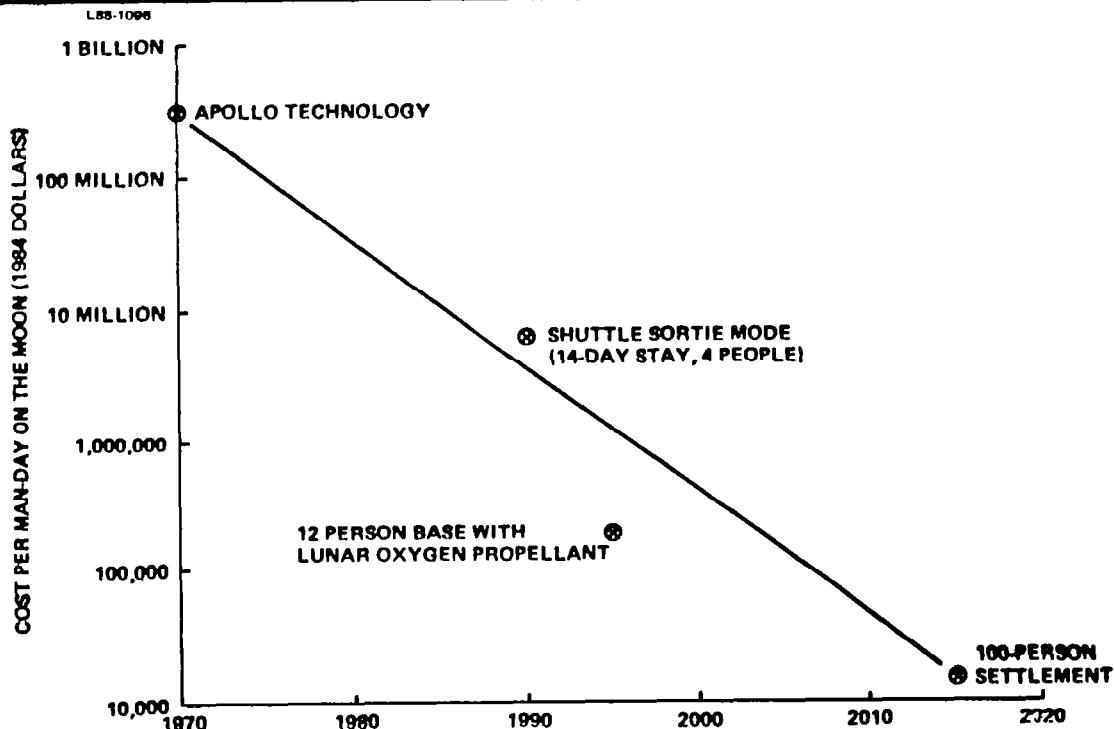


Figure 26



be able to support a growing lunar settlement for about the same transportation effort described in this paper for a twelve-person base. If so, we would by then have achieved over four orders of magnitude in economies compared to Apollo technology (Fig. 26).

## CONCLUSIONS

This preliminary examination of a return to the Moon is clearly upbeat. It is timely to begin to fit the idea into long-range planning for the future of the U.S. civilian space program (Fig. 27).

# Conclusions

---

- **Apollo costs are not applicable to a return to the moon**
- **Return to the moon is compatible and synergistic with the planned space station**
- **ROM cost is \$1 billion per year added to on-going and planned activities**
- **A long-range goal of near-self-sufficiency is conceivable**

Figure 27

## ACKNOWLEDGMENT

The Organizing Committee gratefully acknowledges the work of many individuals who contributed to the success of the Symposium. Particular thanks go to Ms. Katherine Burgess and her associates in the UAH Division of Continuing Education who handled all logistical arrangements. Ms. Doris Ruddle of UAH bore the principal burden of correspondence with the speakers and aided the Chairman in many other ways. Ms. Camille Jernigan of Universities Space Research Association had much of the responsibility for preparing the publication of the Abstracts and this Proceedings.

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Areas covered in the symposium included: Policy, Legal and Economic aspects of Space Industrialization; Communications; Materials Processing; Earth Resource Observations; and, the role of Space Carriers and a Space Station.

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