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INDUSTRY WORKSHOP ON LARGE SPACE STRUCTURES - EXECUTIVE SUMMARY

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16. Abstract

A NASA-sponsored Industry Workshop on Large Space Structures was convened at Langley Research Center on 24–26 February 1976. A number of structures specialists from seven major aerospace companies participated. This document summarizes these experts' informed predictions about the future structures to be fabricated/assembled/erected in space, and, as such, presents a composite appraisal of what the Aerospace Industry views as the critical structural technology developments needed to support NASA space missions in the 1985–2000 time frame. Details are given in report NASA CR 144997, "Compilation of Company Presentation and Responses to a NASA Key Issue Questionnaire on Large Space Structures."

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PREFACE

This report was compiled by the McDonnell Douglas Astronautics Company (MDAC) as Task 21 under Contract No. NAS1-12436 with the National Aeronautics and Space Administration (NASA), Langley Research Center, Hampton, Virginia. Its purpose is to summarize and record the individual industry presentations and workshop discussions that took place at LRC on 24-26 February 1976. The subject of the presentations and workshop was confined principally to large space structures technology; although other mission-related issues (e.g., materials development, controls, and sensors) were identified, this report does not attempt to discuss them. This report is an executive summary; a supplementary report contains an unedited compilation of Company Presentations and Responses to a NASA Key Issue Questionnaire on the subject. (NASA CR-144997).

At NASA-Langley Research Center, the work was monitored by S. J. Scott, head of the System Design Studies Program, with E. T. Kruszewski and E. C. Naumann acting as Technical Advisor and Task Manager. Ellis Katz, of Rockwell International Corporation, acted as Task Leader and principal author of the executive summary report. The task was administered and the conference convened under the direction of R. H. Christensen, Manager of the Systems Design Studies (Structures) Program, MDAC.

A number of other individuals assisted in developing the material presented in the documents of this task and in reviewing the drafts. In particular, the significant contributions made by the following are hereby acknowledged: J. M. Hedgepeth of Astro Research Corporation; R. H. Nansen, J. W. Straayer, and H. W. Klopfenstein of the Boeing Aerospace Company; F. F. W. Krohn, and J. D. Forest of General Dynamics Corporation; C. A. Nathan of Grumman Aerospace; H. Cohan and B. Ellis of Lockheed Missiles and Space Company; G. W. Smith of Martin Marietta Corporation; and R. Johnson, Jr., and D. L. Williams of McDonnell Douglas Astronautics Company.

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INTRODUCTION

The Outlook for Space Study, Reference 1, and a related study, Reference 2, have identified potentially important new space initiatives and missions which could serve a wide range of human needs.

A number of these missions have been shown to require large light-weight structures, with dimensions of from one hundred to several thousands of meters. Figure 1 illustrates three representative missions.

The NASA/OAST Space Technology Workshop, which grew out of the referenced studies, has evaluated these future missions and has designated the development of such large structures as a critical technology need. Four generic classes of large space structures have been identified for detailed assessment of the needs: (1) booms; (2) deployable antennas; (3) erectable antennas; and (4) erectable platforms. These four classes are illustrated in Figure 2.

To assist the NASA in assessing the needs and in defining the required technology program, the Langley Research Center convened an Industry Workshop on Large Space Structures at Hampton, Virginia, on February 24-26, 1976. Industry participation included Boeing, General Dynamics, Grumman, Lockheed, Martin, McDonnell Douglas, and Rockwell. Each participating company presented its reponse to the following seven questions:

(1) What future space missions will utilize each of the generic structures identified in the Space Technology Workshop (booms, deployable antenna, large erectable antenna, and erectable platforms)?

(2) What are the benefits of these missions?

(3) What are the specific technology requirements for each generic structure?

(4) What specific roles can ground testing (components, subscale, and full scale) play in verification and demonstration of the required new technology?

(5) What specific roles can small Shuttle/Spacelab experiments play in verification and demonstration of the required new technology?

(6) Will manufacturing in space of basic structural elements be required? If so, will it be feasible and cost effective?

(7) What is the nature of a candidate R&D program to accomplish the required new technology?

At the conclusion of the prepared responses, working groups were organized to consolidate industry positions on these topics. This report presents a composite summary of the views expressed in the Industry Workshop.

WORKSHOP CONCLUSIONS

As was expected, the industry views coincided on a number of issues, but differed widely on others. In each case, the result was judged beneficial to the technology planning process. Where there was general agreement, our confidence in the position was enhanced; where there was disagreement, we learned that there were specific needs to resolve the issue. The following *conclusions received general industry agreement*; specific needs to resolve other issues are presented in the technical discussion section of this report.

(1) One of the major goals identified by the Space Technology Workshop was to develop and verify the technology for large space structures by 1985. The Industry Workshop concluded that this goal is realistically achievable if an orderly buildup of research, engineering, and test activities is begun now.

(2) Technology development is most critically needed in the following areas: definition of large space structural configurations and their structural elements; assembly and joining tech-

References:

1. Outlook for Space, NASA Report SP-386, 387, January 1976.
2. Study of Commonality of Space Vehicle Applications to Future National Needs; Aerospace Corporation, Report ATR-75 (7365)-1, March 1975.

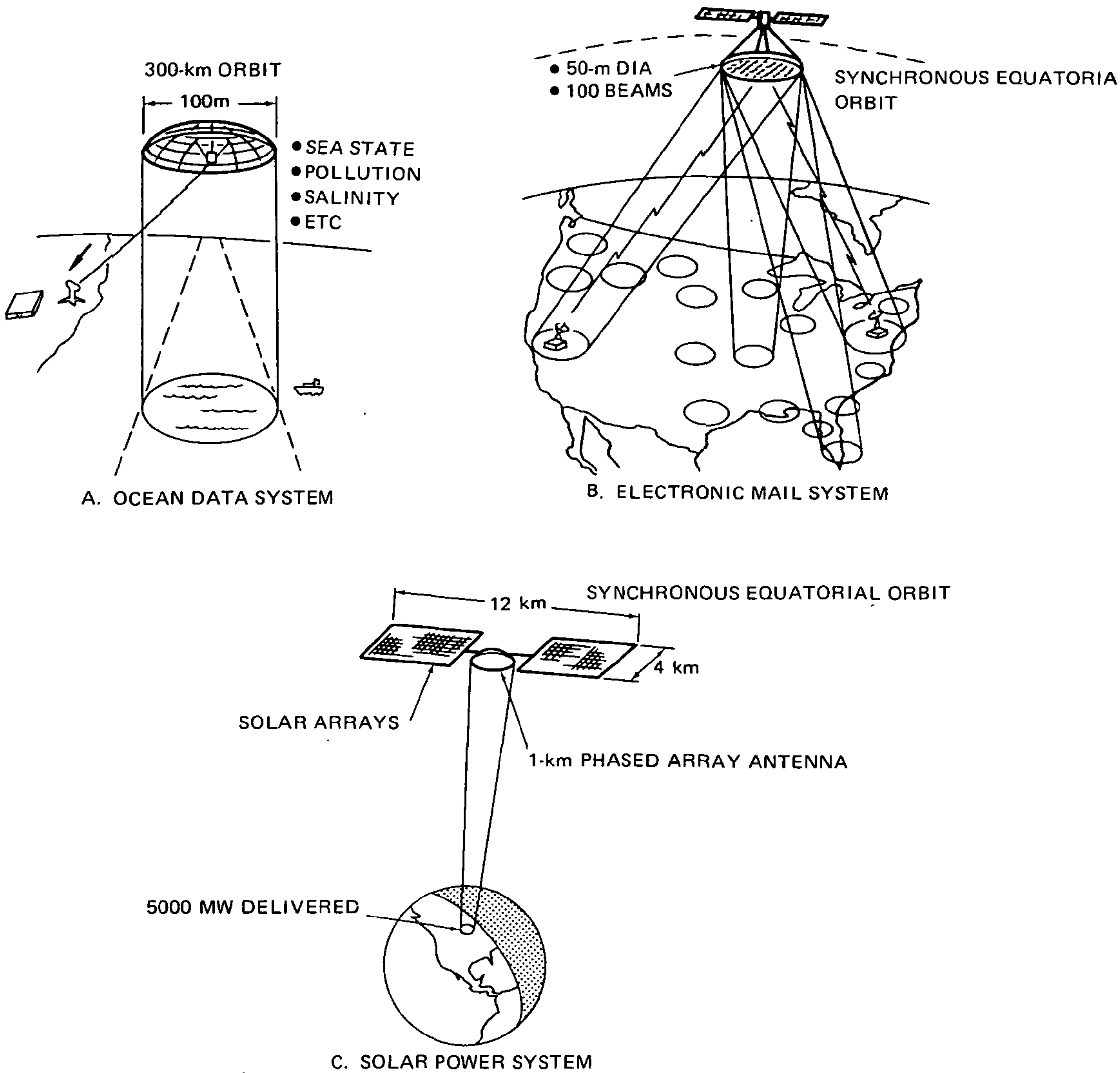


Figure 1. Representative Future Missions Requiring Large Space Structure

niques and the associated role of man; improved modeling and scaling laws (see below); interaction between control systems and structural responses; design criteria for long-life, thermally resistant structures; and material characterization.

(3) At their full-scale dimensions, large space structures will withstand only those loads imposed by the space environment and system operations. To design such structures for a ground environment would be prohibitive in terms of material and launch costs. Further, to ground test the full-scale structure in a simulated space environment would not be practical. Therefore, it is necessary to develop predictive modeling techniques and scaling algorithms so that design margins and the associated structural weight may be held to acceptable limits. These techniques must account for the natural and induced environments (static and dynamic) and for manufacturing and assembly tolerances. To assure accurate prediction, design approaches may have to be limited to those which can be modeled with high fidelity.

(4) Ground experimentation will be extensively applied to components, segments, and subscale

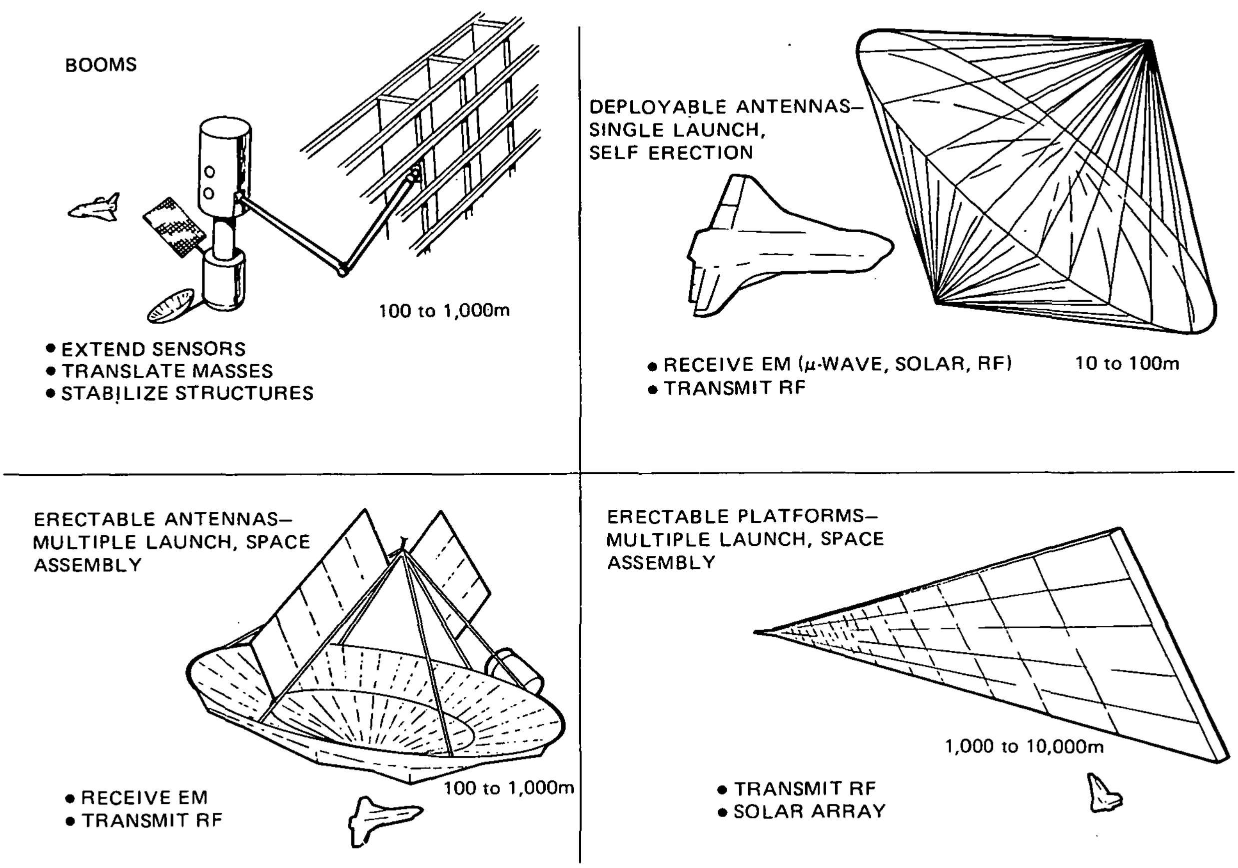


Figure 2. Classes of Large Space Structures

models of the space structure; space experimentation, using Shuttle, will be needed to calibrate and validate modeling techniques and scaling laws. In addition, space experimentation will be required to develop and validate assembly and associated operations.

(5) Manufacturing in space is feasible and must be developed for the larger class of structures. Initially, "prefab" structural elements, delivered by Shuttle and assembled with astronaut interaction is probably the most practical and cost-effective construction process.

TECHNICAL DISCUSSION

This section presents the summarized results of the Industry Workshop. Greater detail is presented in the full compendium of the industry responses given in NASA CR144997.

MISSIONS AND COST BENEFITS

Figure 1 illustrated three representative future missions requiring large space structures. The Ocean Data System would employ three satellites, each using a deployable antenna to monitor the ocean's surface. The Electronic Mail System would use multibeam erectable antennas to provide communication services to 100 local post offices in each of the largest 100 cities. The Space Power System would use a phased-array erectable antenna platform to transmit up to 5,000 megawatts of RF power to ground receivers. The power could be generated by solar voltaic (erectable platform) arrays or by solar concentrators driving Brayton-cycle turbines.

In earth observations, as represented by the Ocean Data System mission, benefits could be realizable in improved yields from the fishing industry and reduced fuel and operating costs in the oceanic shipping industry.

In communications, as represented by the electronic mail mission, benefits may be realizable in reduced postal labor costs and faster service. In addition, the larger antennas, with their narrow beams, would allow better utilization of the limited radio frequency spectrum within a restricted geographic region.

Solar power systems offer the potential of clean and safe power while conserving natural resources. The possibility of energy export to other nations was also considered.

TECHNOLOGY NEEDS

Structural Configurations

A substantial body of experience has been obtained in the design and application of deployable antennas. The 10-meter-diameter Lockheed flex-rib antenna (Figure 3), currently flying on the ATS-6 satellite, is an example of this type of structure. At larger diameters, say 20 meters and greater, stored energy in the furled structure may be unequal to deployment functions, and surface accuracy requirements may lead to other concepts, such as the one shown in Figure 4. If the packaging efficiency of the 10-meter antenna can be extended to the larger sizes, it should be possible to accommodate a 100-meter-diameter deployable antenna

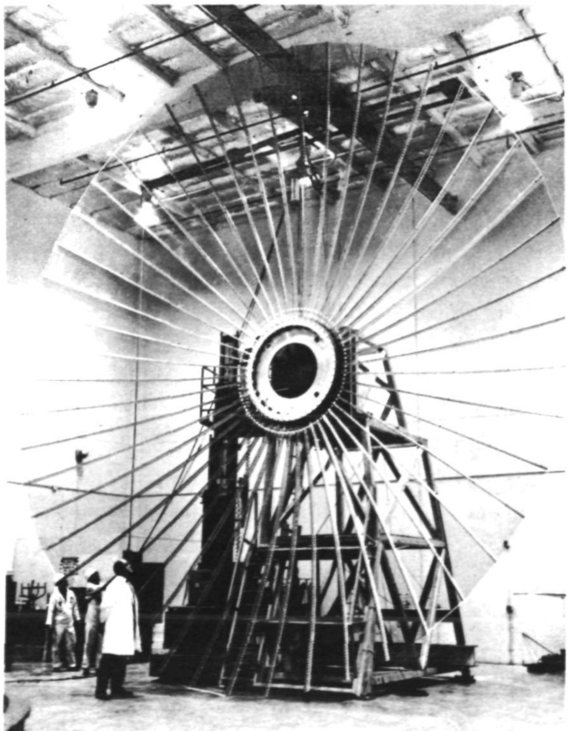


Figure 3. ATS F&G Ten-Meter Parabolic Spacecraft Antenna (Lockheed)

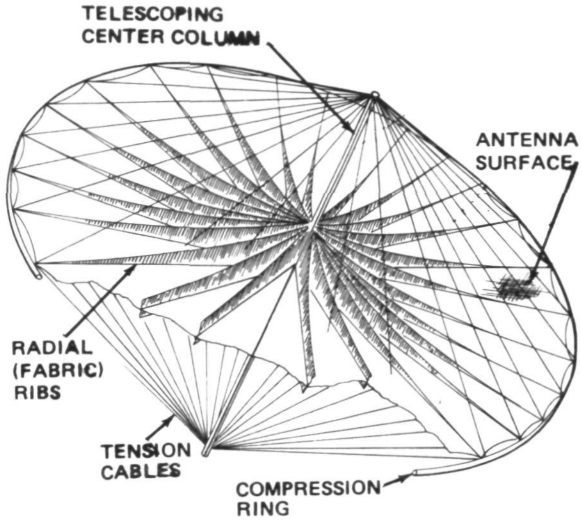


Figure 4. Maypole (Deployable) Antenna Concept (Lockheed)

within the Shuttle cargo bay. There is, however, a serious question as to whether, at the 100-meter size, the reflective surface could be held to millimeters of accuracy without active control. Configuration studies are needed to evaluate the packageability, deployment, and surface accuracy of antennas up to 100 meters.

Space experience with booms of the class discussed herein has been limited to the positioning of 11 kg (25 pound) masses at distances up to 8 meters; this capability was demonstrated on several Apollo missions where X-ray and mass spectrometer instruments were positioned outside the contamination field of the spacecraft. The remote manipulator system (RMS), Figure 5, now under development by the Canadian government,

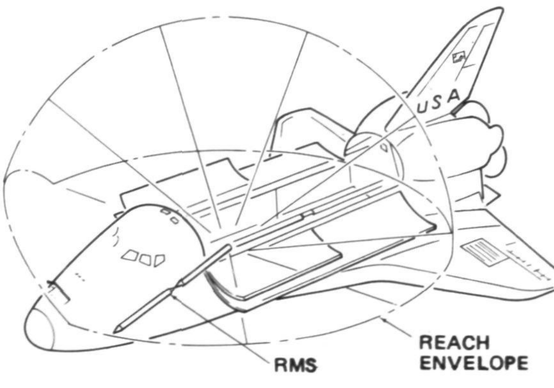


Figure 5. Shuttle Remote Manipulator System (Rockwell)

will be used to deploy and retrieve 30,000 kg (65,000 pound) masses at distances of 15 meters from the Shuttle's cargo bay. For booms of a much larger class (upwards of 100 meters length), experience has been limited to preliminary analyses and conceptual models, including innovative concepts such as cable-stiffened booms.

Future space construction activities will require devices to translate structural elements and orient them at the point of assembly. Long, articulated booms may be used for this application as illustrated in Figure 6. These devices could also have postconstruction application for positioning auxiliary system elements such as antennas in nonocculted regions of the configuration. They could also have application as very large lightweight structural members which in combinations form overall assemblies. These requirements pose the need to develop articulating booms which would be lightweight, highly damped, and capable of positioning relatively large masses at distances of 100 to 1,000 meters from the driven base.

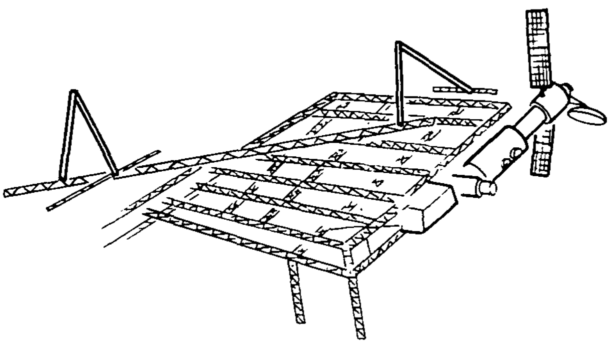
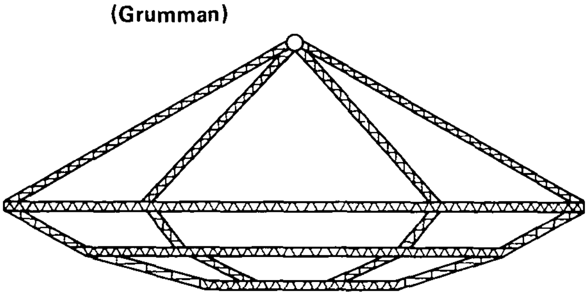


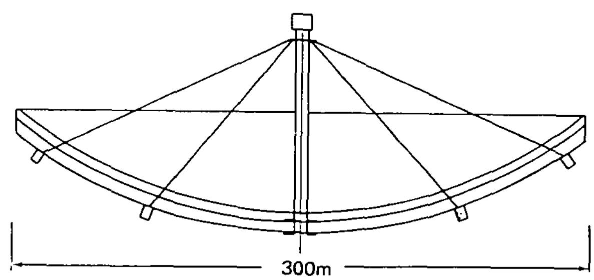
Figure 6. Construction Base Assembly Booms (Grumman)

As contrasted to the experience base for deployable antennas, there is little more than a conceptual study base for erectable antennas and platforms. Figure 7 illustrates several types of large structures which have been under study. Each application and configuration has its own peculiar set of requirements; all, however, share the need to be lightweight, to be sufficiently stiff, to retain an acceptable contour accuracy, and – most importantly – to be erectable in the space environment with a minimum of support systems and construction energy.

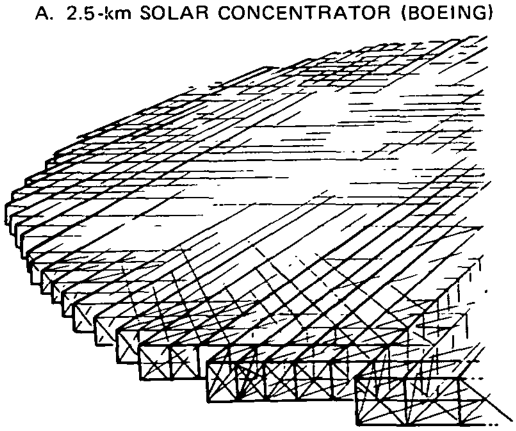
The need for light weight is reflected by the estimated transportation cost (Shuttle-based) of $1,000-2,000/kg of structure delivered to geo-synchronous orbits. To minimize weight and cost, therefore, it is necessary to limit the design loads to very light forces of the space environment.



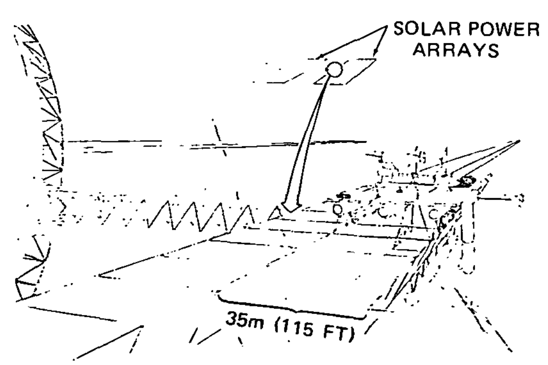
A. 2.5-km SOLAR CONCENTRATOR (BOEING)



B. 300-m PARABOLIC ANTENNA (GENERAL DYNAMICS)



C. 1-km PHASED-ARRAY ANTENNA (MARTIN)



D. SEGMENT OF A 5-km SOLAR ARRAY (MDAC)

Figure 7. Concepts of Erectable Structures

When compared with the 1-g earth environment, these space forces, as shown in Figure 8, are noted to be much lower in magnitude. Although not shown, loads associated with gravity-gradient torques and pressure asymmetries must also be reacted. Under the most severe conditions, the worst of these loads would be an order of magnitude less than would be experienced in the ground environment.

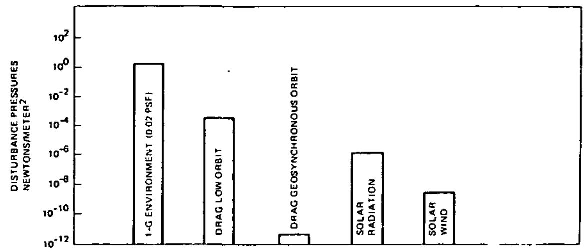


Figure 8. Environmental Forces on a 1-km-Diameter Antenna (Rockwell)

Structural Elements

An erectable antenna or platform could require hundreds or thousands of similar structural elements in its construction. There is a need, therefore, to define a set of standardized elements which could be used to construct a variety of structural configurations for a range of mission applications and requirements. In addition to being structurally efficient, the elements must lend themselves to fast, minimum-effort joining techniques and to high-density packaging for transport within the Shuttle.

Figure 9 illustrates two different concepts for a beam type of structural element. After these and other concepts are evaluated for various structural applications, the most promising concepts should be selected for design and proof-of-concept tests.

Assembly and Joining

Construction of large erectable structures could involve the space assembly of hundreds or thousands of structural elements and system components. There is a need to determine the most economic balance between manual and automated modes of assembly; the requirements derived from this analysis could affect structural and joint design as well as support equipment (e.g., construction booms).

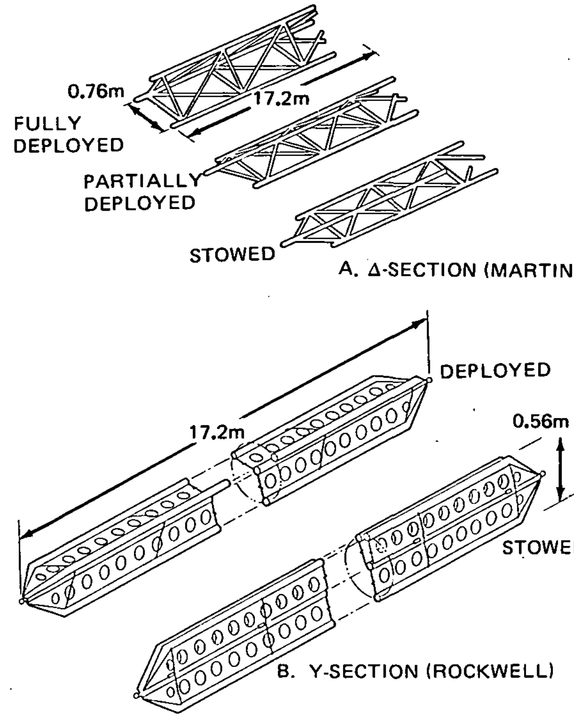


Figure 9. Structural Element Concepts

Figure 10 illustrates several concepts of assembly. Figure 10A emphasizes the role of astronauts; this concept might be limited to early-term structures emplaced by several Shuttle launchings. Figure 10B shows a more advanced concept for the assembly of a 300-meter erectable antenna. This concept would utilize a construction base to provide resident accommodations for the crew, to dock the cargo-carrying Orbiters, and to assemble the antenna. Figure 10C shows one of the more advanced concepts applied to the construction of a 1-kilometer-diameter space power antenna. This type of construction might utilize automated devices to perform many repetitive assembly operations supplemented by remote teleoperator and local astronaut functions for fine alignments and adjustments.

The efficient joining of structural elements and assemblies in space poses one of the most challenging technology problems. Joint design and operations will affect the time and energy needed for assembly, the structural weight, the electrical power transmission requirements, and the need for surface contour control. Figure 11 shows two basic joint concepts: multipoint attachment and single point attachment. Studies and tests are required to evaluate these alternatives, as well as the issues of fused versus mechanical joints and pinned versus rigid joints.

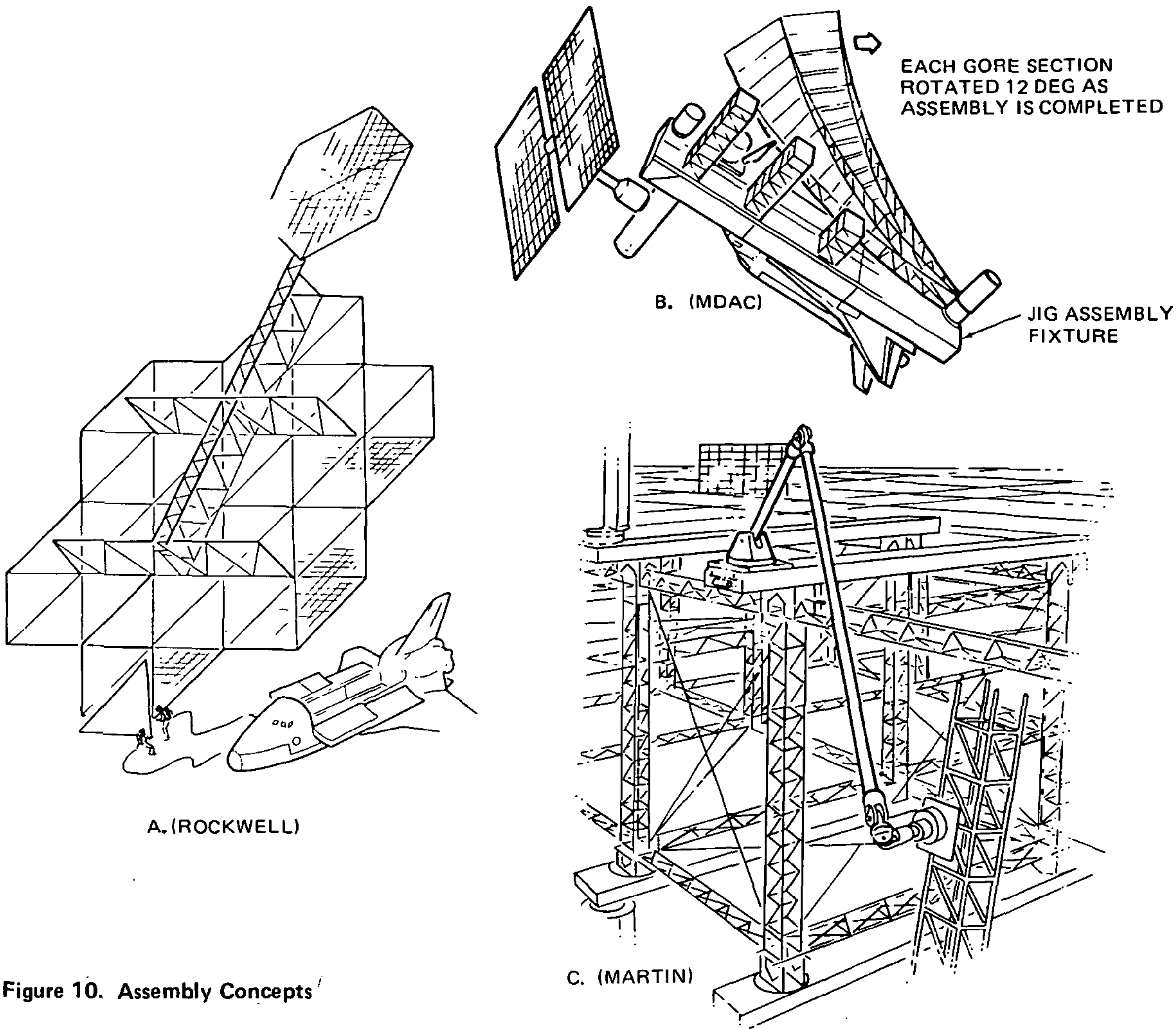


Figure 10. Assembly Concepts

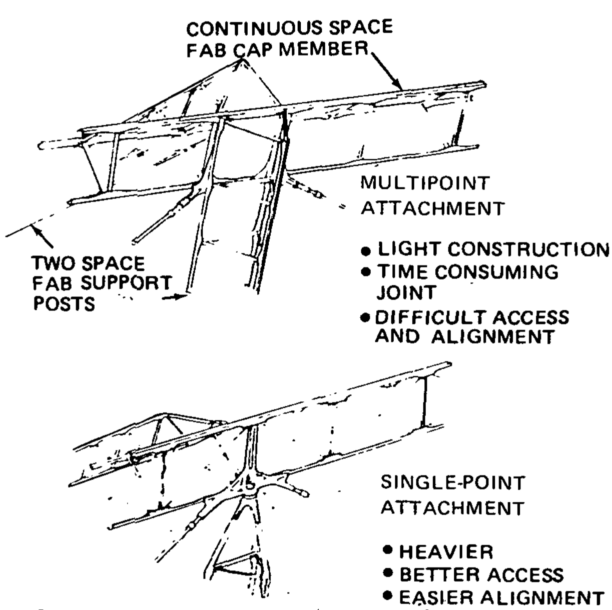


Figure 11. Joint Concepts (Grumman)

Analysis and Design Methods

The size and special characteristics of large space structures dictate that the first time such an assembly assumes its operational configuration, it will occur in orbit. This situation creates unique problems for both the designer and the test engineer.

The designer will need a completely new set of criteria – for the determination of loads, design margins, fatigue life, thermal distortion, and so on. He will require analytic techniques for modeling the structure and simulating the natural and induced operational environment. His techniques must also account for practical limitations in manufacture and assembly: minimum gages, tolerance build-ups, and joint play. As engineering data are accumulated in subscale ground and flight tests, the designer must improve his modeling and scaling technology so that a full-scale space assembly program can be undertaken with confidence.

The test engineer must therefore work with the design engineer to devise a series of experiments that supports the progressive build-up of knowledge and confidence in the modeling and scaling technology.

Table 1 lists some specific areas in which modeling and scaling technology should be developed.

Particular emphasis must be given to modeling and simulation techniques which would allow the extension of ground-test data obtained in a simulated zero "g" environment to the space operational situation. These techniques would not only account for scale differences, but would also accurately predict the effects of physical constraints and boundaries and combined environments. It is probable that some of these techniques would utilize computerized analytical models interacting with test specimens to provide effective simulation. The Modalab system, shown schematically in Figure 12, and currently used by Lockheed for determining structural response, is an example of techniques that will be required in the future.

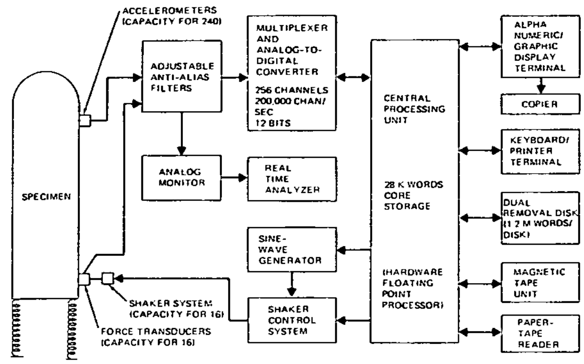


Figure 12. Modular Block Diagram Configured for Modal Testing (Lockheed)

Interactions Between Structures and Controls

Because large, lightweight configurations are inherently more flexible than conventional aerospace structures; typical structural frequencies would fall well below 0.1 Hertz. In this range, a large structure might have a dynamic mode which is nearly resonant with the pointing control frequency – leading to costly control system complexities. Therefore, there is a need to seek an overall structural stiffness which achieves a balance between control complexity and weight.

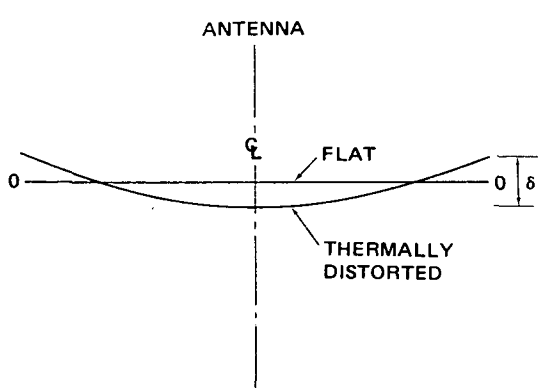
Table 1. Analytic Areas Requiring Model Development

Area	Requirement
Thermal-Dynamic Response	Long-period dynamic response of structure to sharp-edge thermal excitation.
Gravity-Gradient Excitation	Precision determination of gravity gradient forces and moments using series expansion techniques.
Control-Structural Dynamics Interactions	Simulation of a large number of structural nodes/modes in combination with distributed actuators and sensors.
Energy Dissipation	Dissipation of vibratory energy through extended elastic structures in one "g" and zero "g" and at vacuum and ambient pressures (include nonlinear damping).
Digital Control Systems	Digital processing of multisensor data from large structure, including some form of mode acceleration compensation.

Erectable antennas and platforms vary widely in their requirements for surface contour accuracy. The surface of a reflector antenna should be maintained within millimeters of its nominal contour, a multibeam lens antenna within centimeters. These stringent requirements tend to limit the size of such devices to several hundred meters or less, and may also require active contour control. On the other hand, phased-array antennas offer the option of electronic phasing of their emitting elements to compensate for surface irregularities; therefore, size is not limited by contour accuracy. Solar arrays and collectors are much more forgiving; local surface areas may be displaced minutes of arc (degrees in some configurations) from the ideal contour without suffering undue losses.

Thermal Effects and Materials

Thermal effects are critical in the structure design of antennas with a required contour accuracy in millimeters and long-life RF power array antennas with surface temperatures which could exceed 500 K. Figure 13 shows the surface distortion estimated for various sizes of a flat phased-array antenna made with state-of-the-art construction and materials. This thermal flexing may create fatigue problems over the orbital life of the antenna, as shown in Figure 14. There is a need, therefore, to develop structural design concepts which would have low thermal expansion, long life, and good fatigue resistance. As indicated in Figure 15, composite mate-



DIAMETER (m)	δ (cm)
152	2.2
304	8.3
456	18.0
608	31.5

Figure 13. Predicted Thermal Distortion of a Phased-Array Antenna (Lockheed)

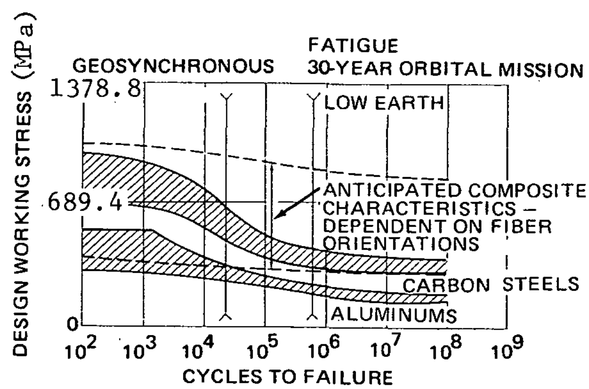


Figure 14. Fatigue Resistance of Materials (Rockwell)

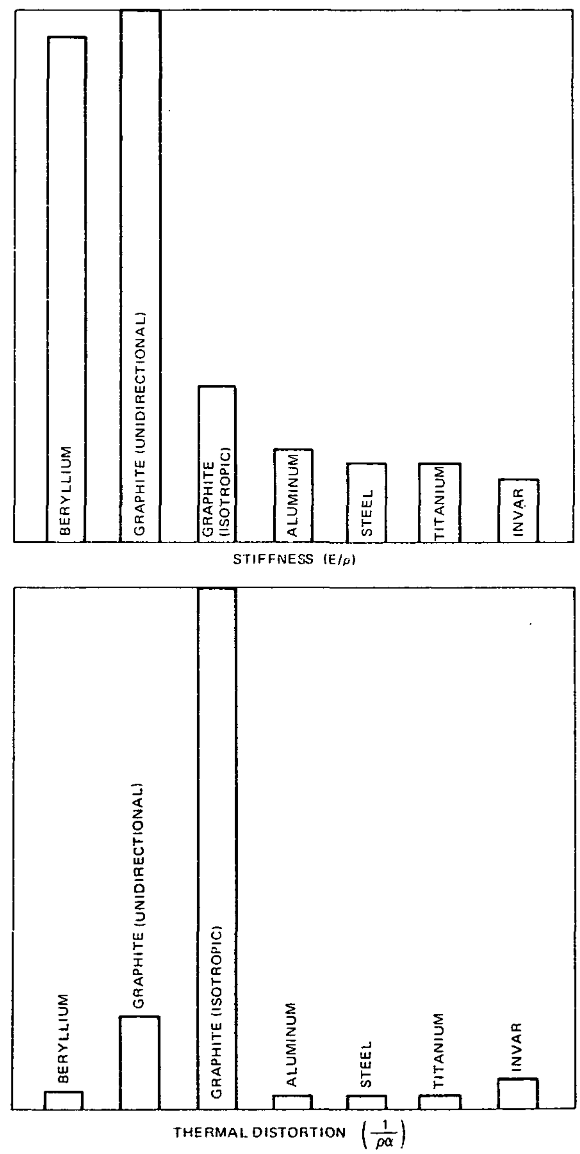


Figure 15. Material Merit Functions (General Dynamics)

rials appear promising for large space structures; however, additional research and testing are required in the following areas: performance at high temperatures, operational life, outgassing effects, and potential means for providing electrical conductivity in some applications. Until such research and testing are accomplished, the selection of materials (including metallics) for many applications will be conditional.

Space Manufacturing

Space manufacturing is defined as the on-orbit fabrication of structural elements from material stock. The process promises (1) reduction of launch costs by reason of high-density packaging of the transported materials, and (2) reduction of on-orbit construction crew size, operations, and support by reason of automated fabrication and assembly functions.

With respect to packaging density, preliminary studies suggest that the Shuttle cargo bay could be volume-limited (up to 30% below the weight capacity) when carrying "prefab" compacted structural elements. The resulting launch-cost penalty could be negated if the high-density raw stock were carried to orbit for manufacture of the elements in space.

Space manufacture also promises to reduce the costs of orbital construction. The utilization of semi and fully automated processes for element fabrication, joining, and assembly could substantially cut the need for space construction crews and their support systems. Figure 16 shows a concept for the semiautomated manufacture of longitudinal 30-meter-deep structural members of up to 1 kilometer long; manufacturing rates are estimated at 1 to 2 meters per minute.

With respect to these promises there is a need to define the operational requirements, evaluate the economics, and develop the technology necessary for implementation.

Initially, "prefab" structural elements, delivered by Shuttle and assembled with astronaut interaction is probably the most practical and cost-effective construction process.

ROLE OF GROUND EXPERIMENTS

Extensive ground tests of essentially all components, structural elements, subassemblies, and scaled models of complete assemblies are necessary – with due regard to total cost. Tests of the following types will be required:

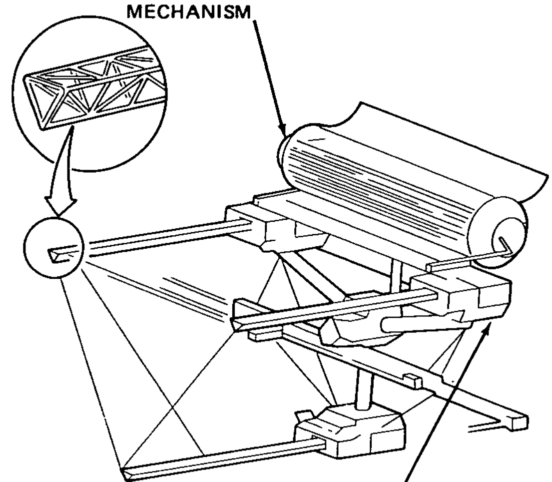


Figure 16. A Concept for Space Manufacturing (Rockwell)

- Deployment tests to evaluate concepts and designs for linkages, mechanisms, joints, and structural elements. Such tests might utilize subscale models with counterbalancing to offset the effects of gravity, and with some testing in vacuum chambers. Full-scale deployment tests for end-item development may also be performed, within facility limitations. These limitations could affect the nature of the tests, the allowable size of the test specimens, or the test environment.

- Thermal deformation tests of subassemblies exposed to simulated thermal and vacuum environment.

- Erection and assembly tests at the subassembly level with counter balancing in large vacuum chambers, and provisions for astronaut operations. Some testing may also be performed under ambient conditions, such as in the Langley Lunar Landing Facility.

- Structural dynamics tests for calibration of analytic and scaling models. Tests would also be run on full-scale joints to develop load-carrying and damping characteristics.

- Thermal-vacuum tests on materials, coatings, lubricants, bonding, and special sensors and instrumentation.

- Evaluation tests of potential space manufacturing processes.

Although a number of ground test requirements have been identified, it is generally agreed that existing facilities can probably be utilized to meet most of these re-requirements. The major exception to this is in deployable structures, where the size of the deployed structure may be greater than existing facilities can handle. Of particular importance is the need to firmly establish the test requirements to support early planning for long-lead-time ground facilities.

ROLE OF SPACE EXPERIMENTS

Due to the high relative cost of space experimentation, emphasis must be placed on obtaining high-confidence predictions of structural performance, reinforced by ground tests as described above. However, space experimentation has a unique and necessary role; i.e., to verify – in the total operational environment – the operations and structural technology needed to deploy and assemble large structures in space. Types of space tests to be performed include the following:

- Tests to evaluate man/machine functions and to establish astronaut and special equipment requirements

- Tests to verify deployment and assembly operations

- Tests to evaluate and validate structural joining methods

- Tests to evaluate the effectiveness and accuracy of candidate alignment techniques and the associated instrumentation. Similar tests to evaluate thermal deformation

- Tests to determine the dynamic response of the structure to assembly, control, thermal, and other environmental excitations

- Tests to evaluate active means for maintaining/correcting the surface contour

- Tests to validate the methods used to predict the dynamic interaction between structure, attitude control, and surface control systems

A number of these tests could be accommodated within the planned Advanced Technology Laboratory (ATL) program. The first of the planned Shuttle/Spacelab/ATL missions is the 17th Shuttle flight currently scheduled for mid-1981. Subsequent missions might occur at intervals of 3 to 6 months. There is a need to define the candidate large structures experiments and to assess the capability of Shuttle to achieve the requisite test objectives in an economic and timely manner.

A possible schedule for the space experiment program is given below:

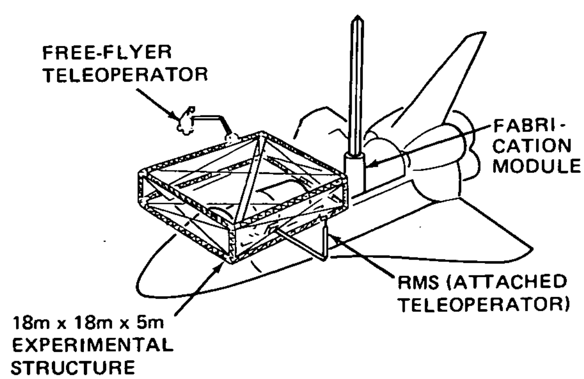
1980-85

- Tests of structural elements and scaled systems on Shuttle/Spacelab/ATL. Figure 17 shows a concept for such a test.

- Long-term exposure of critical parts (joints, connectors, actuators, instrumentation, etc.). Some tests may be accomplished aboard the Shuttle/LDEF (Long Duration Exposure Facility).

1983-87

- Tests of full-scale systems (e.g., antenna) or major assemblies (e.g., solar power array) on the Shuttle.



TESTS
• JOINTS
• MATERIALS
• SPACE MANUFACTURING
• ALIGNMENT
• SUPPORT EQUIPMENT

Figure 17. Concept for Space Experiment (Grumman)

1985-90

- Tests of space manufacturing/techniques for major elements of a future system (e.g., Space Solar Power System).

CANDIDATE R&D PROGRAM

To assure the availability of the large space structures technology to support future missions, a comprehensive R&D program must be defined. The program should be planned to support the following mid-80's objectives:

- Development of deployable antennas to 100 meters in size which can be packaged within the Shuttle.

- Development of erectable space structure configurations with unit weights (mass/area) one-tenth or less than those of conventional aerospace structures.

- Development of basic structural elements which can be compactly stowed within the Shuttle bay and efficiently joined in orbit.

- Development of on-orbit assembly, erection, and alignment operations and techniques which could support the efficient construction of erectable structures hundreds of meters in size.

- Development of active surface control techniques and systems which can measure and correct surface deformations to within millimeters of accuracy.

- Development of attitude control techniques for the pointing and stabilization of very large, inherently flexible space structures.

- Development of space construction support equipment, including articulated highly-damped booms at least 100 meters in length.

- Development of analysis and simulation techniques which can extend subscale ground test experience to high-confidence predictions of full-scale performance in the space environment.

- Development of lightweight long-life structural materials with high stiffness and low thermal expansion properties.

- Development of an operational, technical, and economic data base which could support the development of a space manufacturing capacity for structures of 1 kilometer size and greater.

To achieve these objectives in an orderly, economic manner by the mid-80's, a comprehensive program should be implemented within GFY 77. The initial phase of this program is, in fact, currently underway with studies of large space system applications and requirements (e.g., solar power stations) at JSC and MSFC. Other studies are in progress at LaRC (structural concepts and design criteria), JPL, and LeRC (large power antennas). In addition, MSFC and JSC are undertaking studies of construction techniques and the role of the astronaut. Additional studies are required to develop concepts for basic structural elements and to plan a series of space experiments which may be flown aboard early Shuttle/Spacelab (ATL) missions.

The results of these studies would be used to prioritize the alternative concepts, materials, and techniques for design definition and exploratory lab tests. These initial tests should be underway in GFY 78 so that the design of full-scale space test hardware could commence by GFY 79. Ground tests of the hardware elements in deployment and environment simulation facilities (in some instances simulating astronaut interactions) should proceed in GFY 80. By mid-GFY 81 initial space experiments would be underway aboard the ATL missions. Early space tests would concentrate on joining and assembly operations, astronaut participaton, and competitive structural elements. Subsequent space experiments, supported by comprehensive ground simulation tests, would extend the data base to the performance of structural assemblies, the adequacies of modeling and simulation techniques, and associated subsystems (e.g., active contour control). By the mid-80's, space tests would have demonstrated the performance of prototype operational structures such as deployable and erectable antennas. The final objective of this series would be secured by space tests of a prototype space manufacturing and assembly facility.

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