NASA Contractor Report 2964

Industry/Government Seminar on Large Space Systems Technology - Executive Summary

Sinclaire M. Scala

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Sinclaire M. Scala
General Electric Company
Philadelphia, Pennsylvania

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and Space Administration

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1978

PREFACE

This report was prepared by the General Electric Company as part of a task under Contract No. NAS1-9100 with the National Aeronautics and Space Administration (NASA), Langley Research Center (LaRC), Hampton, Virginia. Its purpose is to summarize the invited and contributed papers and to record the highlights of the forum/issues panel during the Industry/Government Seminar on Large Space Systems Technology held at LaRC on January 17-19, 1978. The seminar was sponsored by the Large Space Systems Technology Program Office, Langley Research Center. This executive summary is a companion publication to the Proceedings of the Large Space Systems Technology Seminar (NASA Conference Publication 2035, Volumes I and II, 1092 pages).

At NASA/LaRC, E. C. Naumann was task manager and seminar coordinator. A. Guastaferro, Manager of the LSST Program Office, served as general chairman of the seminar. The task was administered by S. M. Scala, Senior Consulting Scientist, General Electric Company, who also served as moderator of the forum/issues panel and prepared this executive summary. E. C. Naumann of LaRC and A. Butterfield of General Electric compiled the two-volume NASA Conference Publication 2035 which contains the detailed presentations that are summarized herein.

Appreciation is expressed to the many industry, NASA, and DOD representatives for their active participation in the seminar, to the seminar staff who handled the many arrangements and to the Langley Technical Editing Branch for assistance in preparing the seminar reports for publication.

CONTENTS

INTRODUCTION

Because the age of the Space Transportation System (Shuttle) is imminent, it is time to seriously consider missions requiring spacecraft much larger and more versatile than currently in use, and to utilize these mission models to define the necessary technological advances required to achieve these new system requirements in a timely, cost effective manner.

Whereas existing spacecraft have been limited in size and consequently limited in capabilities directly related to size, it is clear that earth satellites need not have the limitations of size imposed very much longer. One can readily visualize the sequential orderly development of families of spacecraft whose capabilities grow with size. As experience is gained with the deployment of antennas, or the erection of antennas and platforms, one can foresee the use of facilities in space for the fabrication and assembly of modular elements into huge special purpose or multipurpose platforms, antennas and space stations. It is clear, however, that while size will no longer be a limitation per se, there are other barriers to be overcome, including the need to clearly establish the utility of these potentially large space systems, their economic viability, and their technical feasibility. Without these studies and demonstrations, there will be little credibility and hence a low probability of continuity.

Preliminary studies (e.g., refs. 1-8) conducted by NASA, DOD, and their contractors indicate that in order to meet future user needs, large antennas, platforms, and manned spced stations will be required either in low earth orbit or geosynchronous orbit. Specific applications have been identified and evaluated, with relevance to human and/or defense needs as the basic measures, in a series of recent studies.

One of the most comprehensive recent studies was that undertaken by a special Outlook-for-Space Study Group. Following this study, two NASA reports were issued in January 1976: "Outlook for Space" (ref. 1) which identified potential future space activities and "A Forecast of Space Technology" (ref. 2) which provided a comprehensive forecast of technology which might reasonably be expected to be available for the effective management of information, energy, or matter in space during the last two decades of the 20th century. These broad studies served as the impetus for establishing additional working groups and task forces whose recommendations could be implemented via future programs. One of these technical groups concluded that large area space structures would be required to achieve the majority of the principal objectives and missions developed in "Outlook for Space."

In order to help NASA identify the technology developments required for proposed missions, a three-day industry workshop was held at NASA/LaRC in February 1976. At this workshop, representatives of major aerospace companies were asked to respond to a Key Issues Questionnaire, the responses to which are documented in two NASA reports: "Industry Workshop on Large Space Structures" (ref. 4) and an associated "Executive Summary" (ref. 5).

In March 1977, the Langley Research Center was named lead center of a multi-center multidisciplined planning activity with the mission of defining and developing critical technology for use in large space systems in the years 1985 to 2000. The Large Space Systems Technology (LSST) Program Office evolved from these planning and program definition activities. An LSST Seminar was sponsored by the LSST Program Office to provide a forum for the more effective interchange of ideas, plans and program information needed to develop the required large space systems technology. The format of the seminar was closely aligned to that of the 1976 workshop because of the effective interchange obtained during that endeavor.

The seminar organizing committee utilized invited papers, contributed papers, and a panel discussion to maximize potential benefits for each of the participating organizations. The invited papers were used to provide industry with an insight on the views of the LSST Program Office, NASA Headquarters and background information on shuttle/astronaut interfaces and to provide NASA with information on industry views by means of a new questionnaire. The contributed presentations were more or less equally divided between industry and government. These papers emphasized on-going or planned in-house technology development in support of large antenna systems or large platform systems and addressed at least one of the following: mission requirements, structural concepts, materials, controls, structural alignment, thermal control, metrology or packaging/shuttle-interface considerations. Finally, the last session of the seminar was devoted to a forum, whose purpose was to provide an opportunity for industry and government representatives to present their views on significant and controversial issues, to answer questions from the attendees and, in general, to focus attention on critical LSST needs and approaches.

The proceedings of the seminar are documented in NASA Conference Publication 2035 (ref. 9). This executive summary provides an overview of the presentations and highlights of the comments and recommendations of the forum panel.

INVITED PRESENTATIONS

LSST Program Overview

The opening presentation by A. Guastaferro, LSST Program Manager, began with a statement of the broad objectives of the Large Space Systems Technology (LSST) Program which are to define and develop the necessary technology for large space systems and associated subsystems for projected NASA space missions in the 1985-2000 time period. It is a goal of LSST to make these systems economically viable as well as technically feasible by focusing on those activities which are believed to provide the greatest benefit to a variety of future systems.

The operational shuttle will provide the nation the opportunity to utilize new space systems that generically require:

- Significantly larger structures
- More complex control systems
- Deployment, assembly and/or fabrication capability on orbit
- Integrated design of structure/electronics/power
- Greater surface accuracy
- Longer operational lifetimes
- Greater multidisciplinary interaction
- More reliable predictive capability

It is envisaged that the LSST Program will reduce design and development costs for future large space systems by providing developed and verified structural concepts, analyses and design procedures for a range of sizes and configurations; significant advances in a variety of complementary areas of technology are also anticipated. LSST will also reduce transportation costs by developing concepts having high packaging efficiency and multi-mission capability. This cost saving will be accomplished by utilizing a systematic method of evaluating technology requirements based on needs, technology gaps, and mission commonality to establish program content and priority.

The LSST Program is managed by NASA-Langley (LaRC) as the lead Center. The LaRC-LSST Program Office (LSSTPO) is supported by the technical expertise of four NASA centers and JPL through their designated representatives. This expertise is integrated into a program that is responsive to the needs of large space systems technology developments. This multi-discipline management approach provides the opportunity to utilize effectively the roles and missions (expertise) of the participating NASA centers.

As part of the overall LSST development process, systems studies will be performed on selected missions to identify the large space systems and the technology developments required. These identified focus missions will be used as focal points for integrating and continually updating and evaluating the technology being developed in all areas of the program. Tentative focus missions in the 1985-2000 time frame include:

- Communications
- Global crop forecasting (soil moisture determination)
- Weather forecasting
- Pollution monitoring
- Astrophysical research

Figure 1 is an artist's representation depicting the theme of the seminar. Figure 2 is an artist's rendition of a large space platform with some of the complementary areas of technology identified.

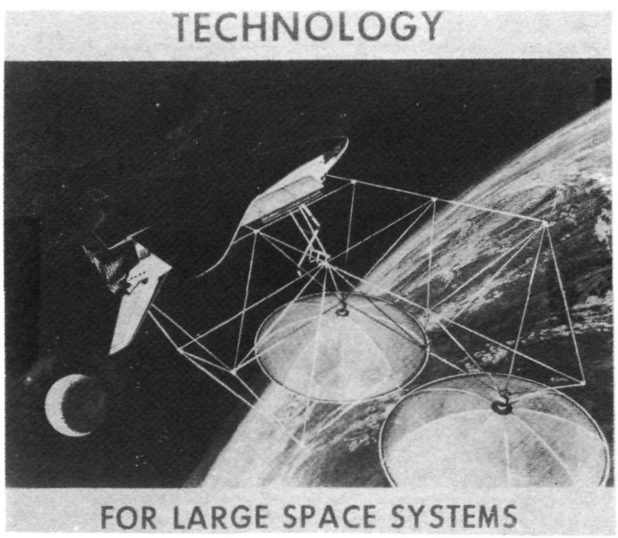


Fig. 1 - Technology for Large Space Systems (NASA LaRC)

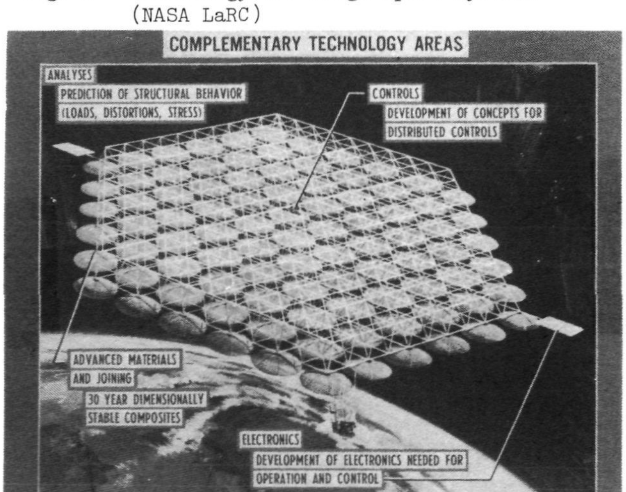


Fig. 2 - Complementary Technology Areas (NASA LaRC)

TECHNOLOGY NEEDS AND FUTURE MISSIONS

A forecast of NASA's future needs and missions, and of the trends of technologies relevant to the projected needs, was presented in a NASA Headquarters paper. Figure 3 is an artist's concept of a large multipurpose communication platform in geostationary orbit that can serve many user needs. A space platform with such capabilities represents a challenge to the technical community and is typical of a new trend that is developing.

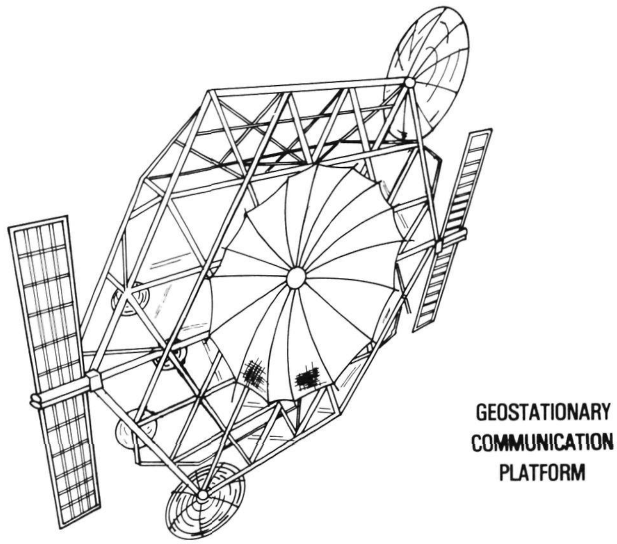


Fig. 3 - Geostationary Communication Platform (NASA Headquarters)

That is, that there will be a shift from earth satellites, which are relatively simple and with complex ground terminals, to reliable complex multiple-use systems in orbit which are able to communicate with many, simple, user-oriented ground terminals.

The specific challenges in technology growth introduced by large space systems can be visualized from the projected space-system size growth plot in figure 4.

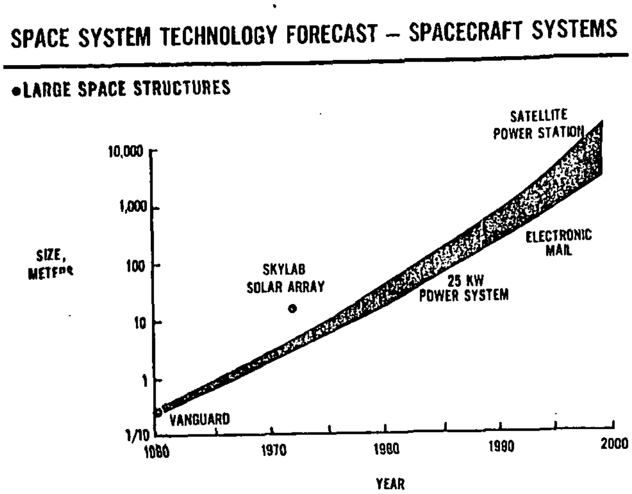


Fig. 4 - Forecast of Future Space System Size (NASA Headquarters)

Today's systems are of the order of tens-of-meters in size; in the 1980's we can expect sizes of hundreds-of-meters, and probably in the 1990's a capability for systems on the order of kilometers.

Note that the missions shown in the figure are representative of projected mission models and are not part of NASA's committed five-year plan.

OAST has developed a technology forecasting model for use in technology development planning activities. While this model does not predict the future, it can be useful in providing realistic assessments of technology developments. A listing of near term missions which have LSS technology requirements includes the following:

- Global communications land mobile services
- Public services communications satellite
- Pinhole (solar X-ray) satellite
- Geostationary platform
- 250 KW power module
- Solar electric propulsion stage (SEPS)

Turning now to NASA OAST's far term mission model, conceptual missions have been evolved which allow us to bound the future in LSS technology requirements, and as such are a representative segment of potential future programs. These missions include:

- Automated planetary station
- Space-based radio telescope
- Geological mapping system
- Global communications system
- Global navigation system
- Space power system
- Space station
- Teleoperator vehicle system

Examination of these mission models indicates that in addition to the technology of large structures, the following technologies will become important:

- Active figure control in order to achieve high surface precision (see fig. 5)
- Advanced composite materials to achieve weight reduction and lower transportation cost
- Advanced automation technology in order to achieve significant breakthroughs in operating costs
- Efficient high capacity power systems and associated technologies.

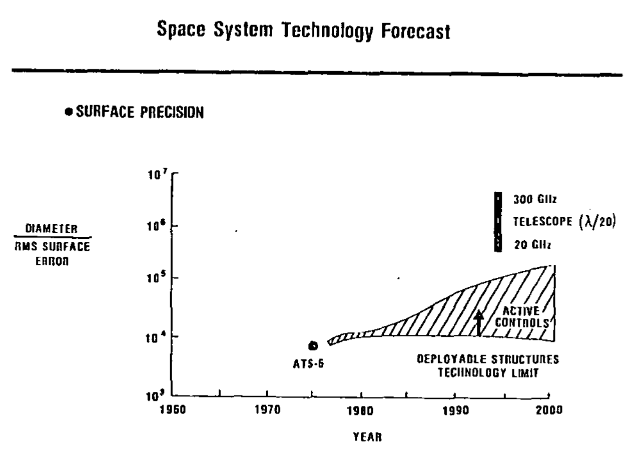


Fig. 5 - Space System Technology Forecast-- Surface Precision (NASA Headquarters)

SHUTTLE ORBITER CREW/ASTRONAUT INTERFACES

A Johnson Space Center report describing the current shuttle orbiter configuration was presented. The report concentrated on basic orbiter crew interfaces, remote manipulator system (RMS) operational capability, and planned activities for early flights. It also reviewed some of the facilities at JSC that are used to verify crew interfaces.

The crew module is divided into three principal elements. The flight deck is the primary work area, the mid-deck the primary off-duty area, and the airlock provides access to the payload bay. The forward flight deck is the control station for the pilot and commander during boost, reentry and landing, and can be used on orbit as required. The aft flight deck has provisions for the mission specialists, the payload specialists, and for on-orbit operations (including the RMS controls and displays). The RMS is controlled by two 3-degree-of-freedom (DOF) hand controllers for translation and rotation control. It has selectable automatic and manual modes of control and four coordinate reference systems. The RMS has a maximum reach of 15.2 meters, maximum tip force of approximately 66.7 newtons and maximum tip speed of 0.61 meters/sec. The payload base has provisions to support extravehicular activities (EVA) as depicted in figure 6.

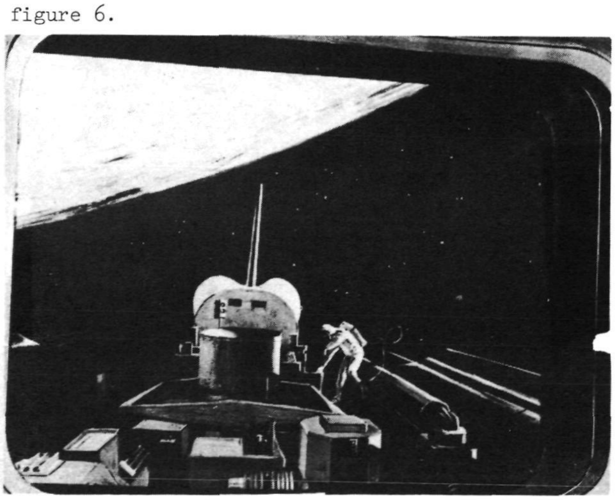


Fig. 6 - Payload Bay EVA Interfaces (NASA JSC)

A portable EVA work station is available to support payload related activities. It is designed to attach to hand holds or bridge fitting interfaces. The station provides crewman foot restraint to allow two-handed operations and temporary stowage of EVA tools.

The first six flights of the shuttle are part of the orbital flight test (OFT) program to test the orbiter capability and prepare it for operational status. Payload activities will be kept to a minimum during the OFT series.

At JSC, a mockup and development laboratory (MDL) houses the manipulator development facility (MDF), the orbiter full scale mockup, a precision air bearing table, and the orbiter trainer. The MDF contains a RMS functionally similar manipulator, mounted near a simulated aft flight deck with functional controls and displays. It utilizes helium-filled, neutrally ballasted inflatables to enable the manipulator arm to move them in and out of the simulated orbiter payload bay.

DESIGN CHECKLIST QUESTIONNAIRE

An MDAC presentation pointed out that designers of commercial and military aircraft are able to refer to a detailed set of federal air worthiness requirements and/or military specifications which have evolved over the years. However, in the relatively youthful space vehicle industry there are no uniform governmental regulations, only an incomplete set of general, recommended guidelines (NASA SP-8000 series) for the design of spacecraft structures. Hence, as we begin to consider the design of large space structural systems, it is not too early to consider the codification of specific design guidelines which will be helpful both to NASA and to designers in industry.

A preliminary checklist questionnaire was distributed at the seminar requesting a response from the participants and/or their organizations. Data and recommendations were solicited in response to a design checklist on the following areas of interest:

- Load analysis
- Thermal analysis
- Structural analysis
- Stabilization and control of flexible large space structures
- Material characterization tests
- Structural tests

The responses generated via this and other similar surveys would be useful in defining areas of uncertainty or technology deficiency and thereby indicate where research and development is necessary to provide satisfactory design tools.

CONTRIBUTED PRESENTATIONS

Large Antennas

JPL report. - JPL reported on two large antenna concepts recently investigated. One of these concepts is the Orbiting Deep Space Relay Station (ODSRS), shown in figure 7.

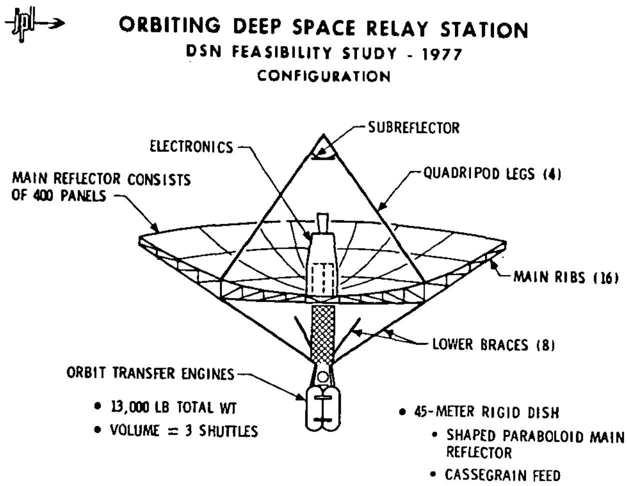


Fig. 7 - Orbiting Deep Space Relay Station (JPL)

The advantages of such a system over earth based tracking stations were enumerated, and four required technology developments were identified as:

- Assembly in space
- Ten-year cryogenic preamplifiers
- Ten-year high precision attitude control
- Ten-year power system

If these technology advances can be demonstrated reasonably soon, the ODSRS could be operational in the 1986 time frame.

Another concept requiring a large antenna is that of very long baseline interferometry (VLBI). VLBI techniques have been used by radio astronomers to obtain maps of celestial radio sources at previously unrealizable levels of angular resolution.

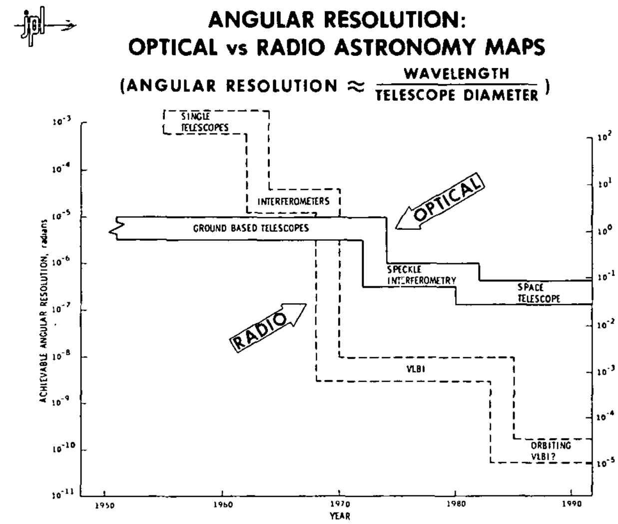


Fig. 8 - Angular Resolution: Optical vs. Radio Astronomy Maps (JPL)

As seen in figure 8, angular resolutions have already been obtained which are three orders of magnitude better than the resolution achieved with photographs or conventional radio interferometers. Satellite-borne VLBI terminals could improve the angular resolution by another two orders of magnitude. Compact celestial radio sources could then be mapped with finer resolution, less ambiguity, and higher efficiency than earthbound VLBI techniques afford. These maps and their time variability would help unravel the physical processes that govern some of the more enigmatic celestial objects including quasars, pulsars, x-ray stars, and flare stars.

GSFC report. - A Goddard (GSFC) presentation gave projected requirements for a high resolution soil moisture radiometer which would obtain data useful for run-off predictions, moisture budget models, climate forecasts, and crop yield predictions. The use of long wavelength ($\lambda > 20$ cm) passive microwave measurements will provide the most reasonable approach to remote measurement of soil moisture. Two frequencies are being considered: 1) 1.4 GH_Z, a radio astronomy band; and 2) 611 MH_Z, a proposed radio astronomy band. These frequencies require antenna reflectors 100 meters and 280 meters in size to achieve the desired ground resolution (≈ 1 km). If a phased array antenna were used, several shuttle trips would bring the components into space for assembly and perhaps to build slotted wave guides on orbit.

MDAC report. - An MDAC presentation on design considerations for large space antennas discussed the projected growth of large space systems, typical antenna structural systems, concepts and performance, and required research and development. Figure 9 shows an on-orbit assembly concept for a 125-meter large aperture test antenna. Key elements include the shuttle, a power module, assembly equipment, and a construction module.

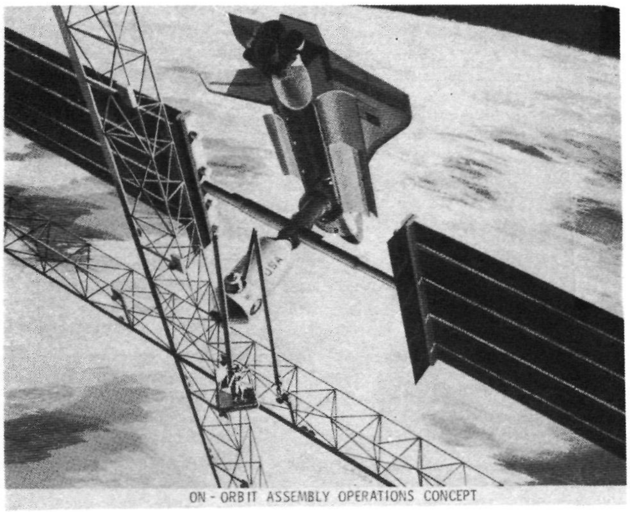


Fig. 9 - On-Orbit Assembly Operations Concept (MDAC)

The presentation stressed the necessity of performing research and development on structures in order to achieve required performance at minimum cost. Activities would include:

- Definition of comprehensive structural criteria for specific missions
- Determination of optimized geometries for truss elements and truss configurations
- Establishment of requirements for joint designs
- Development of candidate structural elements and joint concepts for deployment, assembly only, and on-orbit fabrication and assembly
- Development of material systems for low pressure rapid cure of advanced composite materials.

TRW paper. - In a TRW paper on future technology requirements for large antenna structures, a baseline antenna concept was presented, consisting of a deployable center section and an assembled rib mesh ring (see fig. 10), and technology needs to support the concept were forecast.

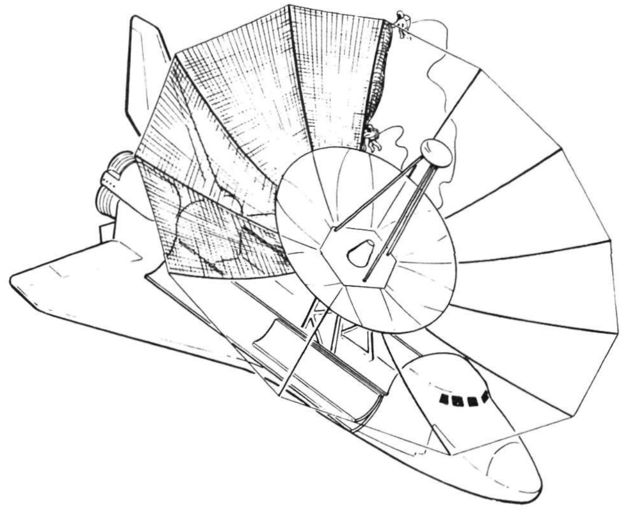


Fig. 10 - Deployable Center Erectable Rim 20-Year Life Communication Antenna (TRW)

Becuase a 20-year life in orbit was contemplated, data were presented on the anticipated degradation of material mechanical and thermal properties with time in the space environment, including large bands of uncertainty in the property data with increasing exposure. As a consequence, it was concluded that basic work is needed on nonmetallic materials, including coatings, to determine their physical properties for extended lifetimes in space. An understanding of the physics of the damage mechanism in space is a requirement. Moreover, extrapolation of short term data (under 10 years) beyond 10 years was thought to be entirely unsatisfactory.

LaRC report. - In a Langley report on the subject of space deployment antennas and electronics, three basic questions were addressed:

- Which deployable reflector concepts will meet the requirements for large space structures?
- How large can we build a deployable reflector?
- What criteria will be used to select an erectable design over a deployable reflector?

Research on antennas for L- and X-band applications resulted in the discovery that a 1-millimeter rms surface accuracy must be achieved for 300-meter-diameter reflectors. This, in turn, requires an on-board structural accuracy measurement subsystem, and an active shape control subsystem. Methods for the prediction of the electromagnetic properties of large deployable antennas will also be required.

There are some basic questions on electronics subsystems for large space structures which must be answered, including:

- How will electrical power, data and command signals be transmitted through a large space structure?
- What type of grounding (fault current bonding) system will be used in a large space structure?
- Can fiber optical techniques be used in large space structures?

General Dynamics report. - In a General Dynamics presentation on the application of geo-truss erectable antennas, attention was focused on three potential satellite systems for the 1985-2000 time frame:

- Direct TV broadcast satellite
- Deep space communications satellite
- Coastal water surveillance satellite

the last of which is shown in Figure 11.

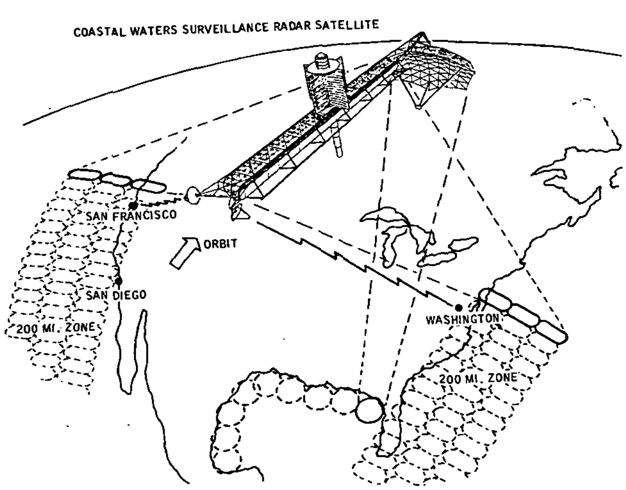


Fig. 11 - Coastal Waters Surveillance Radar Satellite (General Dynamics)

The geo-truss concept provides a natural structural element to use in the deployment or fabrication of these large systems. In general, reflector systems were selected over lenses or phased arrays due to their economy, simplicity and weight advantages. Frequency, beamwidth and gain requirements determine the antenna size and surface contour control. Figure 12 shows the general coverage ranges as a function of frequency, beamwidth and antenna diameter. Pointing accuracy is usually 1/10 of beamwidth. Two degrees would cover a time zone in the US. Increasing the radiated power of the downlink antenna would allow reduced size and cost of

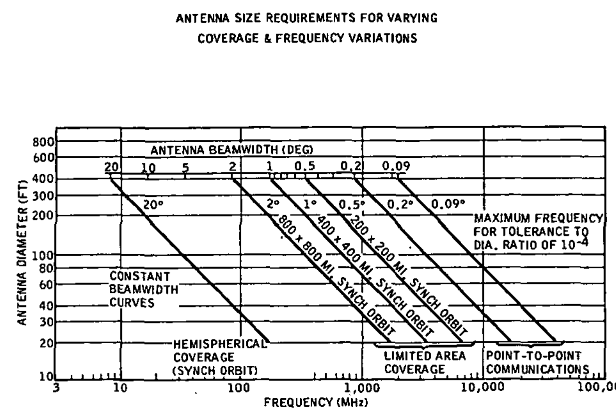


Fig. 12 - Antenna Size Coverage Requirements for Varying Coverage and Frequency Variations (General Dynamics)

a home receiving system. From a technology development viewpoint, structural stiffness is a major concern in meeting the rigorous pointing requirements of these narrow beamwidth systems. For low structural frequencies, complex distributed control systems may be required to meet the goals.

SAMSO report. - A SAMSO report discussed the on-orbit assembly program to develop shuttle-based on-orbit assembly techniques applicable to spacecraft with 30.5 m to 304.8 m diameter sensors. This program includes deployment and check-out in the vicinity of the shuttle, transfer of array or array sections to high earth orbit (HEO), and rendezvous docking and activation in HEO. This is to be accomplished with the minimum number of shuttle launches and must be compatible with other large spacecraft requirements. Figure 13 shows the upper stage influence on concept selection.

UPPER STAGE INFLUENCE
ON CONCEPT SELECTION

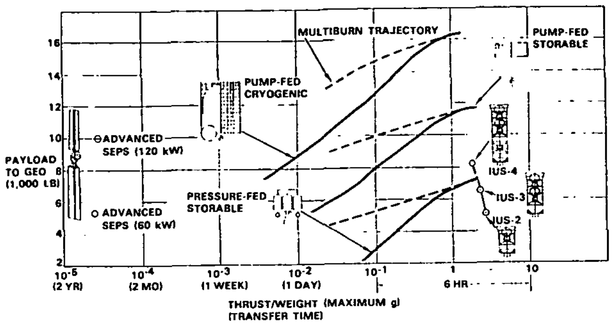


Fig. 13 - Upper Stage Influence on Concept Selection (USAF SAMSO)

In particular, to achieve a higher payload weight in orbit and decrease transit time, high thrust-to-weight ratio upper stages are required.

ACCURACY AND METROLOGY

TRW report. - A TRW paper on in-flight optical measurement of antenna surfaces developed a base for a wide variety of applications oriented sensors. Technology requirements were established by the more demanding applications. Therefore, the most stringent demands come from antenna applications: from requirements for fabrication, assembly, test, surface figure monitoring, and ultimately active surface control. This technology may be equally useful for remote attitude measurement of instrument packages, as an aid in docking and as a guidance sensor for satellite retrieval and servicing. Figure 14 shows a schematic of the measurement of beam deformation during fabrication and test.

MEASUREMENT OF BEAM DEFORMATION DURING FABRICATION AND TEST

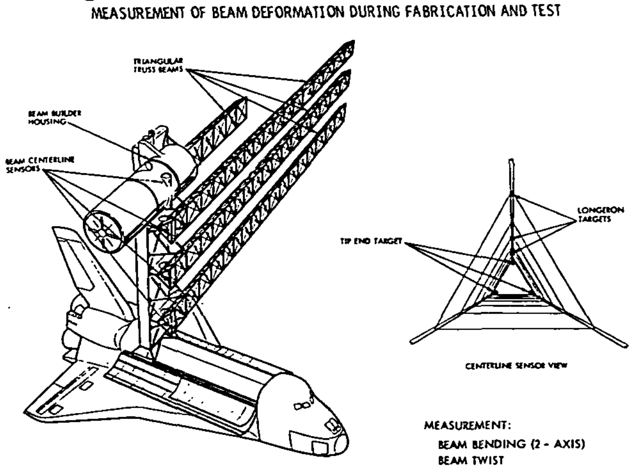
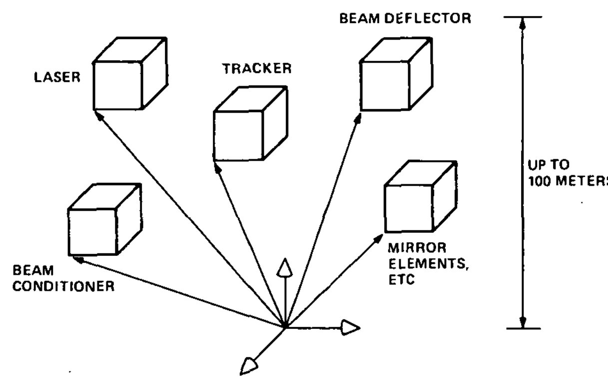


Fig. 14 - Measurement of Beam Deformation During Fabrication and Test (TRW)

GE paper. - A GE paper examined the problem of precision structures. Included were a description of the origin and scope of the metrology problem (see figure 15), the definition of a dimensional control hierarchy, and theoretical performance data on a new precision self-metering structure concept. The self-metering concept has the following claimed advantages:

- Permanent, one-time ground calibration
- No set-up, alignment or calibration is necessary in space
- Calibration is unaffected by storage or handling
- Inherent long-term physical stability, etc.
- No mechanically active or drive parts
- Low power requirements
- RMS error in 10-foot link ≈ 7 micro-inches

ORIGIN AND SCOPE OF THE PROBLEM



FUNCTION REQUIRES GEOMETRICAL INTEGRATION TO 10^{-6}m, 10^{-7} rad
BUT
SYSTEM ELEMENTS ARE PHYSICALLY SEPARATED BY UP TO 100 m

METROLOGY	COORDINATE INTEGRATION	PUT SPATIALLY DISPERSED SYSTEM OF ELEMENTS ON MASTER COORDINATE SYSTEM
	COORDINATE DETERMINATION	DETERMINE MASTER COORDINATES OF ELEMENTS IN REAL TIME TO 10^{-6} m, 10^{-7} rad
STRUCTURE & CONTROLS	MECHANICAL INTEGRATION	ACHIEVE AND MAINTAIN DESIGN MASTER COORDINATES TO 10^{-6}m, 10^{-7} rad

Fig. 15 - Origin and Scope of the Metrology Problem (GE)

SPACE POWER

LaRC report. - LaRC data were presented indicating a forecast requirement for space power and energy which increases exponentially with time (e.g., see fig. 16). A number of the available options including photovoltaic systems, nuclear reactors, MHD, and a possible time frame for the availability of particular power levels were presented. The data showed photovoltaic systems dominating applications in the near term and well into the intermediate term with a laser electric system as an attractive advanced space-to-space power system near the year

2000. There are many technology development challenges associated with all advanced high power energy systems and a substantial research and *development effort will be required to meet the* need for space power.

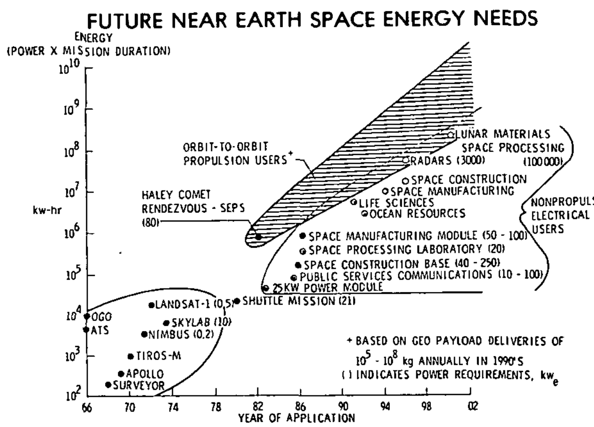


Fig. 16. - Future Near-Earth Space Energy Needs (NASA LaRC)

LARGE PLATFORMS

Rockwell report. - The requirements and concepts for the installation of various types of mission and subsystem equipment on large area space systems were comprehensively delineated in a Rockwell paper. It was noted that equipment installations will be required on large structural platforms with the exception of fully deployable systems or subassemblies with the equipment preinstalled. In most cases, the equipment will be installed in a series of module placement and interconnect operations. This is because the large area of the platform will dictate that some, if not most, of the modules and their functions be located at points distant from one another. Figure 17 illustrates one concept for the installation of modules on a large platform. In this case, the orbiter is shown equipped with two remote manipular system (RMS) arms. The forward arm maintains the orbiter's location with respect to the structure and also provides TV coverage of module placement operations. The second arm has grasped the module at the probe end and executes the detailed installation operations. These operations will be under the control of the crew at the Shuttle aft deck control station.

INSTALLATION TECHNIQUE

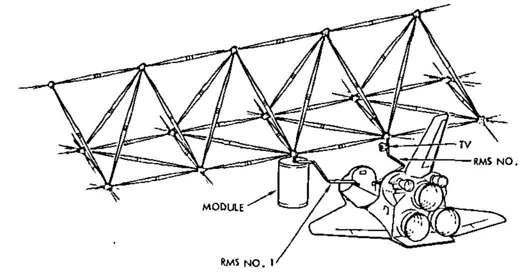


Fig. 17 - Module Installation Technique (Rockwell)

Boeing report. - Structural/thermal considerations were taken into account in a Boeing design concept for a 300-meter truss structure in low earth orbit (LEO). A construction technique involving both deployable and erectable elements compatible with the capability of the shuttle was visualized. An on-orbit assembly procedure with compatible joints was identified for erectable structures. A knee joint concept, applicable to deployable truss structures, containing deployment, latching and damping mechanism systems, was selected for detailed investigation. Temperature distributions were calculated in order to determine the extent of thermal distortion of the large open work truss structure. An example of the results is shown in figure 18. It was found that for $\theta=\pi$ radians, with full eclipse, the radially-varying on-board heating dominated the temperature distributions and was the most critical case for thermal distortions.

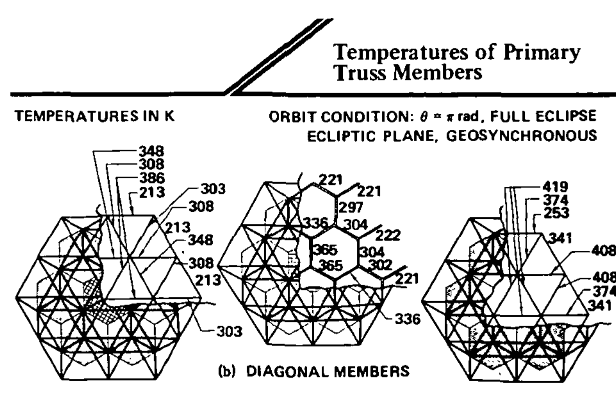


Fig. 18 - Temperature of Primary Truss Members (Boeing)

LaRC Report. - The status of the LaRC development of the nestable column concept for large erectable space structures was reviewed, including results of member and truss component tests and planned assembly studies. Recent studies of alternative member concepts were described and preliminary data on relative efficiency were presented. Figure 19 shows mass/strength curves for several types of graphite-epoxy compression columns. The curves illustrate the superiority of open-construction over solid tubing for lower loads. The point identified as the Boeing design solar satellite power station (SSPS) column illustrates that gigantic columns with longerons made from nestable column sub-elements possess high efficiency.

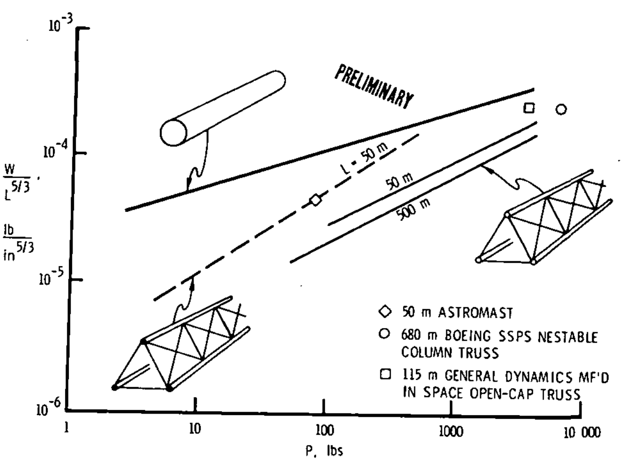


Fig. 19 - Mass/Strength Curves for GR/E Compression Columns (NASA LaRC)

MSFC reports. - In a MSFC presentation on the geostationary platform (see fig. 3) it was pointed out that the idea of such a platform is not new and has been shown to be a cost effective way of accomplishing a wide variety of geosynchronous missions. The platform (which would be assembled in LEO from elements supplied by multiple shuttle launches) could fly as soon as 1986 according to the scenario. In addition to performing baseline studies, MSFC is working with the Office of Space and Terrestrial Applications (OSTA) and LSSTPO, to ensure maximum utility to potential users.

Another MSFC report reviewed plans for the geostationary platform structural system and presented details on the structural configuration, design concept, thermal characteristics, flight load conditions and assembly approaches. An erectable structure, utilizing space fabricated and prefabricated elements, is preferred to a deployable structure to minimize the number of required shuttle launches. In order to obtain experience with the assembly of such large structures, MSFC has been simulating the process by using divers in its neutral buoyancy tank.

A third MSFC report reviewed the characteristics of large space system dynamics and simulations, state-of-the-art limitations, and technology requirements and plans. It was pointed out that experience with both skylab and shuttle taught the necessity of taking a system focus during the concept development and design phases.

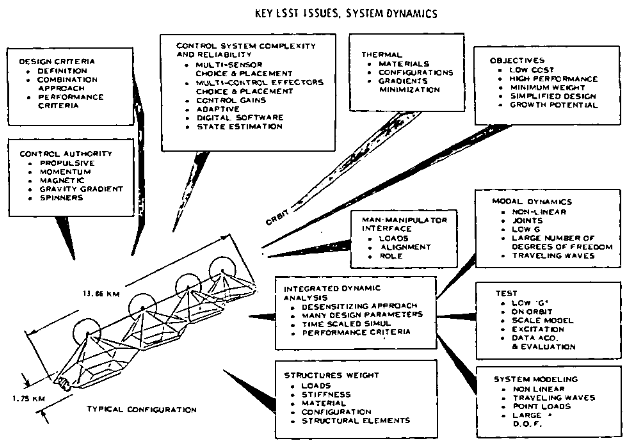


Fig. 20 - Key LSST Issues System Dynamics (NASA MSFC)

Figure 20 lists some of the key issues in various disciplines important to system dynamics and associated trade-off studies. For example, the modeling of nonlinearities is a key area, and whether to design the structure for stiffness requirements or depend on control systems to provide the equivalent stiffness is another. Control authority source is very important, as well as sensor choice, location, and control logic. In the area of design criteria, the choice of unconservative approaches for parameter variations and methods of combining these in design studies is necessary to achieve low cost/high reliability.

MATERIALS

Boeing report. - The feasibility of using thermoplastic composites in the design and manufacture of aerospace hardware was reviewed in a Boeing presentation. These composites are a relatively new development which offer another dimension in design alternatives, a cost-effective design-to-cost approach using high strength, high modulus, lightweight materials for space hardware. Data were given on manufacturing methods, repairability, cost savings, structural properties and environmental stability. Figure 21 presents manufacturing methods that can be used to produce thermoplastic parts. Other standard procedures, such as injection molding, can also be used. The parts can be readily altered at will by the simultaneous application of heat and pressure. Damaged parts can be readily repaired. These materials have good short-term structural and environmental stability and considerable cost savings over other types of composites. However, little is known about the long term behavior of these materials in the space environment.

LARGE SPACE SYSTEMS TECHNOLOGY
BOEING AEROSPACE COMPANY

Thermoplastic Composites Manufacturing Methods

Laminate consolidation:	• Roll-lamination • Pultrusion • Autoclave-lamination • Press-lamination
Post-forming methods:	• Press (matched-die) • Autoclave-molding • Vacuum-forming • Pultrusion
Bonding/joining methods:	• Fusion • Adhesive-bonding • Mechanical-fastening
Chopped fiber molding:	• Injection-molding • Matched-die
Assembly methods:	• Fusion • Adhesive-bonding

Fig. 21 - Thermoplastic Composites Manufacturing Methods (Boeing)

MSFC report. - An MSFC presentation reviewed general materials requirements for long life large space systems, gave data on typical materials and their controlling properties, examined the influence of the LEO and GEO environment, and summarized materials technology development requirements (fig. 22). The figure shows a broad list of materials and their controlling properties. Examination of the effects of the space environment on material performance led to the conclusion that the LSS performance is critically dependent on materials and that the most significant problem is the 20- to 30-year life requirement.

ORGANIZATION | MARSHALL SPACE FLIGHT CENTER | NAME:
MATERIALS TECHNOLOGY DEVELOPMENT FOR LONG LIFE LARGE SPACE SYSTEMS | DATE:

MATERIAL TYPE	TYPICAL LSS APPLICATION	CONTROLLING PROPERTIES				
		MECH	OPTICAL	ELECT	CoTE	OUTGASSING
COMPOSITES	STRUCTURAL MEMBERS	X			X	X
THIN GAUGE METALS	STRUCTURAL MEMBERS	X			X	
ADHESIVES	JOINTS	X				X
DIELECTRICS	ELECTRICAL/ELECTRONIC SYSTEMS	X		X		X
COATINGS	THERMAL CONTROL REFLECTORS	X	X			X
THIN FILMS	THERMAL BLANKETS MIRRORS	X	X		X	X
WIRE MESHES	ANTENNAE	X			X	
SEMICONDUCTORS	ELECTRONICS, SOLAR CELLS			X		
GLASSES	SOLAR CELL COVERS		X			

Fig. 22 - Materials Technology Development for Long Life Large Space Structures (NASA MSFC)

CONTROLS AND AVIONICS

Rockwell report. - A Rockwell report identified control technology advances required for large space systems. A listing of the new control requirements associated with increased size follows:

- greater environmental effects
- larger control torques and forces
- more flexibility
- no full-scale ground tests
- space assembly

and the associated new performance requirements:

- active figure control
- rapid maneuvers of large systems
- orbit transfer of large systems
- longer life

It concluded with a review of modal control techniques under study at Rockwell.

General Dynamics report. - A General Dynamics report on large space platform control avionics included such topics as simulations, robotics, and antenna/structural interactions. A complete list of avionics areas recommended for advanced technology effort would include:

- Large structure control and stability analysis and prediction techniques
- Rendezvous and docking analysis and simulation tools
- Automated positioning and process control methods

- Analysis of antenna/structural interrelationships, the development of analysis tools, and development of adaptive antenna systems
- Electrical power generation/conditioning/ and distribution methods for multi-kilowatt systems
- Increased emphasis on orbiter payload support software development
- Development of common services accommodations for multiple LSS payload user systems, including data management, communications, pointing/stability, power, and environmental conditioning functions.

An example of some of the ongoing avionics studies is shown in Figure 23.

PROCESSOR AVIONICS SYSTEM ELEMENTS

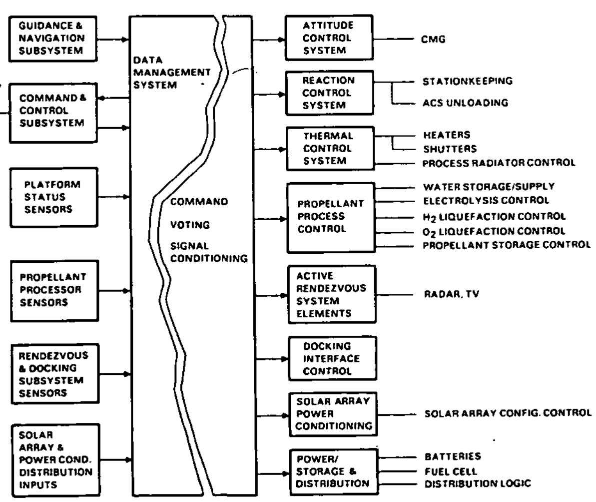


Fig. 23 - Processor Avionics System Elements (General Dynamics)

POST-LANDSAT SYSTEMS STUDY

GE report. - Preliminary results on forecasting and identifying the key technologies of earth resources satellites during the post 1984 period (i.e., 1985-2000) were reviewed in a Goddard/ General Electric paper. Some of the specific key objectives of the study are shown in figure 24.

KEY OBJECTIVES

- **LAND USE – LAND USE AND CENSUS ENUMERATION**
  - CREATE THEMATIC AND LAND USE MAPS
  - DETECT CHANGE IN LAND USE
  - ESTIMATE POPULATION
- **WATER RESOURCES – WATERSHED MONITORING**
  - MONITOR SURFACE SUPPLY OF FRESH WATER
  - MEASURE GROUNDWATER FLOW AND STORAGE
  - INTEGRATE RAINFALL AND EVAPORATION DATA
- **ENVIRONMENTAL QUALITY – WATER POLLUTION DETECTION**
  - DETECT, MONITOR, AND TRACE FRESH WATER POLLUTANTS
  - MONITOR EUTROPHICATION
  - MEASURE SALT WATER INCURSION
- **DISASTER ASSESSMENT – ABRUPT EVENT EVALUATION**
  - MONITOR AND ASSESS DISASTERS
  - MONITOR NON-CALAMITOUS ABRUPT EVENTS

Fig. 24 - Key Objectives of PLACE Study (NASA GSFC & GE)

SPACECRAFT CHARGING

A Grumman report presented the views of the company on the space environmental characteristics of major concern to LSS and stressed the need for more data. It was pointed out that while spacecraft charging studies have been conducted since the early 1970's, little is known about specific discharge mechanisms, plasma interactions and scale effects associated with very large spacecraft. It was noted that plasma interactions could result in any or all of the following:

- Power loss through plasma
- Magnetic/electric field focusing/ acceleration avalanche
- Induced forces/torques
- Increased ion sputtering/radiation damage
- Reduced efficiency of ion thrusters

Some serious concerns arise (see fig. 25) because *many advanced LSS missions require very large area* dielectrics. This introduces the requirement for a large area scaling/plasma interaction flight experiment.

LSS CHARACTERISTICS OF MAJOR CONCERN

- MANY COMPOSED OF VERY LARGE AREA DIELECTRICS WITH INTEGRAL THIN CONDUCTORS – SUSCEPTIBLE TO DAMAGE
- EXTENSIVE USE OF COMPOSITE MATERIALS
- LARGE, LOW DENSITY STRUCTURES – INDUCED FORCES/TORQUES
- LONG LIFE REQUIREMENTS – MATERIAL AGING EFFECTS
- MAY INCLUDE HIGH POWER/VOLTAGE NETWORKS
  - – CURRENT COUPLING/STABILITY
  - – MAGNETIC/ELECTRIC FIELD FOCUSING/ACCEL
  - – ECLIPSE & LOAD TRANSIENT EFFECTS
- LARGE SCALE EFFECTS UNKNOWN
  - – CHARGE PROFILES/DISCHARGE MECHANISMS
  - – EFFECTIVENESS OF CHARGE CONTROLS
  - – PLASMA SHEATH FORMATION/CHARACTERISTICS
  - – $\bar{B} \times \bar{v}$ & WAKE EFFECTS

Fig. 25 - LSS Space Environmental Characteristics of Major Concern (Grumman)

FORUM/ISSUES HIGHLIGHTS

The purpose of the forum was to provide industry and government representatives with the opportunity to present their views on significant and possibly controversial issues, to answer questions from the participants, and in general to focus attention on critical LSST needs and approaches. The members of the panel included:

Mr. Henry Cohan, Manager - Space Technology Lockheed Missiles and Space Company

Mr. Max W. Dienemann, Advanced Systems Engineer, General Electric Company

Dr. James Dozier, Director - Research and Technology, NASA Marshall Space Flight Center

Mr. John A. Fager, Manager - Special Projects General Dynamics, Convair

Captain Paul Heartquist, Project Manager, On-Orbit Assembly, DOD/STS Applications Branch, SAMSO

Dr. Roger W. Johnson, Director - NASA Space Systems, Grumman Aerospace Corporation

Mr. Ellis Katz, Project Manager - Large Space Structure Systems, Rockwell International

Mr. Ralph H. Nansen, Manager - Space Power Systems, Boeing Aerospace Company

Dr. Walter B. Olstad, Chief - Space Systems Division, NASA, Langley Research Center

Mr. Robert V. Powell, Manager - Large Space Antennas, Jet Propulsion Laboratory

Lt. Colonel Harry L. Staubs, Chief - Advanced Technology Concepts, Deputy for Advanced Space Programs, SAMSO

Mr. Wallace R. Wannlund, Manager - Mechanical Engineering, Space Systems Division, TRW

The first question considered by the panel dealt with whether LSS technology development should be focused or unfocused. The panel members thought that a spectrum of technology development was necessary, both focused and unfocused. Those who thought focus was necessary stated that the focus should come from a mission model which would be useful and necessary in establishing technology requirements. On the other hand, technology development should not necessarily be tied to the development of a specific spacecraft because the timetable for the procurement of the spacecraft system would generally not be compatible with the longer range timetable required for successful technology development. Program managers have to contend with ample risk just to meet program objectives without depending on the timing of a technological breakthrough. Hence, technology development should be initiated well in advance of ultimate use, so that application is on a low risk basis. What is needed at this time is an "X series" of structural and system technology developments, analogous to the "X series" of supersonic aircraft. These would begin with laboratory work and analysis on the ground, advance to small shuttle experiments, and finally culminate in large scale demonstrations in space.

The question was posed as to how the LSST program should prove its technology development. There was considerable discussion as to whether this should be accomplished through ground tests, piggyback shuttle experiments or demonstrations. The general response was that all of these steps were vital in order to generate the body of knowledge which would be needed in the future. Moreover, the dynamic testing of very large structures will be our greatest challenge. The panel emphasized the need to conduct meaningful tests which provide a broad data base which can be extrapolated to many applications, thereby minimizing the total cost of testing.

In considering the questions as to how system studies and analysis can enhance technology development and why system studies are worthwhile in technology advancement, the panel felt that system studies provide technology goals in order to focus the technology development; however, in many of the system studies performed thus far, inadequate trade-off data are provided. These trade-off data are necessary so that the technical community can decide how far each of the technology developments should be advanced. System studies not only identify critical technologies early in the development of that system but also help to justify the expenditure of scarce resources in developing the needed technologies; that is, system studies help set priorities.

An issue that resulted in a wide range of responses from the panel members was how LSST should approach technology development for spacecraft applications. Should the approach be through a single spacecraft type, analysis of all potential future mission spacecraft requirements, or the selection of several generic configurations? One view was that the LSST Program should not be overly concerned with either the specific mission or the spacecraft, but should proceed to pick one and get on with the job of developing the technology so that this nation will be ready to take on whatever mission is required at the appropriate time. Another view was that there should be clearly stated criteria for the selection process and that the technology selected for development must be applicable to many different classes of spacecraft. Two criteria that should be used in selecting a generic spacecraft are: 1) that it be marketable; i.e., that many of the users are known, and 2) that it be affordable. It was also pointed out that an important challenge is to prove to the "man in the street" that the shuttle and space are worthwhile; therefore, technology should be focused on something he can relate to his needs. For example, NASA could do a prototype demonstration of a solar power station as a stepping stone to space fabrication, because a reliable power source is vital for space operations.

The Panel then considered the question "Will the sheer size and cost of the future space systems force the aerospace industry to 'agree' on areas of participation so that duplications of technology development do not occur? The general response was that there was a need for competition in order to develop the best technology and, therefore, independent approaches by more than one organization were inevitable. In addition, one should not confuse technology with the end product. Basic technologies are not massive even in a massive system.

A large number of panel members responded to the issue as to what extent a user agency should sponsor large space systems technology development and demonstration at this time, and to what extent should it bootstrap programs which will be conducted by NASA and industry? Some members of the panel felt that, whereas one could not readily specify what constitutes a fair share, user agencies and beneficiaries ought to participate and contribute their fair share to the support of technology development. It will be necessary for NASA to review the requirements, needs, functions, cost benefits, preliminary systems design, and preliminary ideas, all in integrated efforts with industry and other government agencies, if the programs are to succeed. To put up larger more ambitious satellites, of the order of 100 meters, operating at frequencies on the order of 20-30 GH_Z and providing video bandwidths to hundreds of thousands of users, the kinds of systems which just demonstrate the technology would be prohibitively expensive. To implement something such as this requires a consortium that includes common carriers, industry, and the government to win the endorsement, and the confidence of Congress.

The final question addressed by the panel was "What should be done to develop national recognition of the need for LSS?" The consensus was that the need for technology development in the LSS area had to be justified in terms of the ultimate benefits on a national basis. Because money is tight, it will go to the programs with the highest priority, and one can only get high priority if one can show ultimate benefits. It is very important to spell out what large scale mass communication systems, observation systems, space power systems, and space processing systems can do for the people of this nation. Therefore, it is very important to take advantage of early opportunities for affordable missions which have conspicuous benefits. This would put us on the right road. It is important to do some things quickly because the aerospace industry cannot survive the next decade by merely performing paper demonstrations. Once space exploitation is accepted, the large systems required will follow. And, of course, it is necessary to be working on LSS technology to be ready for the large systems.

CONCLUSIONS

Progress has been made, between the time of the NASA/LaRC sponsored 1976 Workshop on Large Space Structures and the 1978 Seminar on Large Space Systems Technology, in identifying future potential missions which require a large space systems technology data base. Preliminary systems studies have begun to identify key technology development needs. In addition, concepts for deployable and erectable antennas and erectable large space platforms have begun to appear. Techniques for automatic fabrication of structural elements on orbit and for erection and assembly in space have been proposed. Some of these ideas have advanced to the stage where proof of feasibility is a logical next step. Proof of technology development must come not only through ground tests but also shuttle-borne experiments on orbit. Because of the long lead times required for technology development (≈ 6 to 8 years), and to minimize future space system program cost and risk, the development of LSS technology must precede the applications. Because the potential future missions are not firm plans, LSS technology development should have multiple applications and address the most critical technical issues.

Specific areas of technology which need attention have begun to be identified. They include:

- Reliable predictive capability of the dynamics of large multi-nodal, multi-modal structures
- Complex integrated control systems including passive and active, distributed adaptive controls
- Cost effective techniques for deployment, joining, assembly or fabrication of structures on orbit
- Greater surface accuracy including high performance metrological subsystems and sensing elements to determine figure distortion
- Concepts for integrated design of structure/electronics/power
- Composite materials with high strength-to-weight ratio, high modulus, low coefficient of thermal expansion and stability in the space environment; long-lived coatings
- Robotics and automation techniques
- Space power and associated technologies

Finally, a key conclusion is that NASA and the aerospace industry should encourage greater participation from potential users, make a stronger case to convince the executive and legislative branches of government, and the "man in the street" of the utility of space and the need for large multi-mission space systems. This need has not yet been firmly established and therefore has not fired up the public's enthusiasm, or captured its imagination and support. An early demonstration of the utility of advanced LSS technology is therefore vital.

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15. Supplementary Notes

Langley Technical Monitor: E. C. Naumann
Final Report

16. Abstract

A NASA-sponsored industry/government Seminar on Large Space Systems Technology was held at the NASA Langley Research Center on January 17-19, 1978. Experts on systems and technologies from every major aerospace company and from NASA centers and DOD participated. A series of invited papers and contributed presentations were given and the meeting was concluded with the convening of a Forum/Issues Panel which addressed critical and controversial issues. This document summarizes the interchange of ideas, plans and program information which took place during the Seminar which emphasized the critical technology developments which the participating experts recommend as being required to support the early generation large space systems envisioned as space missions during the years 1985-2000. Details are given in NASA Conference Publication 2035, "Large Space Systems Technology," Volumes I and II.

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