A Technology Program for Large Area Space Systems

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ABSTRACT

The purpose of this paper is to present the management and technical plans of the NASA to implement an advanced systems technology program for large structures of the 1985-2000 time period.

The NASA Office of Aeronautics and Space Technology (OAST) has established a systems technology program for the efficient development of advanced engineering and operational concepts in support of large space systems.

The program's broad technical objectives and goals that will make future space systems economically as well as technically feasible will be discussed. Examples of possible missions that can utilize the technology developed by the program and potential benefits will be given. The four generic structural concepts (erectable structures, deployable reflectors, deployable platforms, and space fabricated structures) to be developed in addition to the goals of technology areas closely coupled with these concepts will be described. Emphasis will be placed on the specific products gained from the program.

LSST PROGRAM SUMMARY

The broad objective of the Large Space Systems Technology (LSST) Program is to define and develop the necessary technology for large space systems and associated subsystems required for projected NASA space missions. It is a goal of LSST to make these systems economically as well as technically feasible by focusing on those technical activities believed to provide the greatest benefit to a variety of future systems. The following eight areas have been selected for emphasis.

Structural Concepts (Figure 1)
- Structural Concepts-Erectable
- Structural Concepts-Deployable Platforms
- Structural Concepts-Deployable Reflectors
- Space Fabrication

Supporting Technology (Figure 2)
- Analysis and Integrated Design
- Control Systems
- Electronics
- Advanced Materials & Joining

WHY LSST?

It has been the NASA policy to support advanced technology development through the research and technology base advocacy program under the Office of Aeronautics and Space Technology (OAST). It will be the purpose of the LSST Program to extend this research and technology base and to focus the effort in support of the many large area space systems of the future.

As the United States shifts from Shuttle development to Shuttle operations, it is obvious that space systems of the future can take on new dimensions in size complexity, power requirements, etc. Shuttle will not only be the major transportation vehicle but quite likely the construction base for the early systems.

LSST 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. LSST will reduce Shuttle transportation costs by developing concepts which have relatively low masses, high package-ability and multi-mission capabilities.

Although the LSST Program is targeted for the 1985-2000 time period, it is a goal to disseminate technology as soon as it is developed to benefit NASA near term missions. In addition, LSST will strive to utilize proposed near term missions to extend or verify its technical developments.
This will be accomplished by utilizing the technical data provided from the mission or by installing special instrumentation on mission hardware to obtain data pertinent to LSST.

An underlying program objective is to contribute to national progress, not only by enhancing space systems design technology, but also by identifying LSST-produced technologies which can assist in the solution of problems in other sectors of the national economy. These identified technologies will be made available to the Technology Utilization Program for dissemination.

The LSST Program approach to provide the necessary integrated technology for a variety of users of large space systems is somewhat new and has many potential benefits, including the broadening of narrow, individual mission requirements into a broad matrix of requirements. This broadening of requirements greatly enhances the researcher's options and creates an atmosphere conducive to innovative thinking. Another benefit from this approach is the somewhat less stringent time schedule for developing the technology. Thus, the researcher has time to investigate more concepts, thereby enhancing the probability of identifying concepts of broad applicability as opposed to a concept that satisfies only a particular set of requirements.

New technologies in several critical areas for large space systems must be developed in the immediate future to serve the national interest and satisfy NASA/OAST goals. This conclusion has been reached in several comprehensive studies such as Outlook for Space, OAST Space Technology Workshop, OMSF Study of Commonality of Space Vehicle Applications to Future Needs (ATR-75 (7365)-1), Technical Program Plan Recommendations for Satellite Power Systems (NASA WP JSC-10872), and Survey of Future Requirements for Large Space Structures (NASA CR-2621).

To perform the types of Earth resource monitoring, global communication service, solar power generation, and scientific missions envisioned in the Outlook for Space and other studies, large area space systems are essential. The LSST Program will make direct contributions to the design and development of such space systems. LSST will provide the advanced concepts and materials for efficient space systems including structures, guidance and controls, assembly, and operations.

Earth sciences benefit from the synoptic coverage, the periodic viewing, the target signal specificity, and the spatial resolution capabilities of remote sensors in Earth orbit. Large area space systems of improved surface accuracy will provide more bands or channels and different sensors. The large size will increase spatial resolution substantially. The resolution element or footprint of a system, whether optical or microwave, is inversely proportional to the size of the signal collecting optics or antenna. For instance, an Earth mapping system would require an antenna one kilometer in diameter in order to obtain a 3 meter resolution. The scientist's desire for a finer look at the Earth to better understand the geology of the continents, the dynamics of the oceans and the processes of the atmosphere, therefore, can only be met by using larger and more accurate systems. This same principle applies to the sciences that remotely observe outer space. A space telescope used for astronomical observations or a microwave antenna engaged in a search for extraterrestrial intelligence can improve resolution and identify the scientific targets in space if it employs a large primary collecting element.

Space offers a unique environment for performing experiments. For example, the large space radio and optical telescope systems are more viable because space frees them from the interfering effects of the Earth's atmosphere. Even more significant, however, is the use of large area space systems to create laboratories where controlled experiments can be performed utilizing the high vacuum and zero-G environment to discover new fundamental facts about physical processes such as phase changes, chemical reactions and reaction rates, and biological phenomena such as microbial growth.

The first major area of benefits to applications is referred to generically as "Global Services." An example is "Global Information Services" which may be accomplished with a satellite network with a broad range of sensors feeding data into a computer system where it is converted into information to allow people to better understand the resources available to them and to help understand, predict and protect their environment. This type of system can also provide communication links for the transmission of business data, mail, disaster warnings, and mobile public telecommunications.

The second major area of benefits to applications is referred to generically as "Space Industrialization." Two example applications with great potential are space power and space processing. Power generated in space - solar or nuclear - and delivered to other large space systems or to Earth can help satisfy society's energy demands.
without depletion of Earth resources and without environmental insult. Processing of materials in the pressure and gravity minimums afforded by manufacturing plants in space promises to enhance crystal growth yields and to improve yield and quality from other electronic device manufacturing processes. The unique space environment also opens the door for orders of magnitude improvements in biological processing such as required in special vaccine preparation.

Whether in global service or in space industrialization applications, realization of the potential often depends on the development of advanced large space system technology. Large planar structures for construction of the basic space platforms, observatories and laboratories and large subsystems such as booms, heat radiators, optical mirrors and antennas are some of the elements of large space systems requiring technology advances. For example, antennas of various types for Earth observations, space power relay, communications, navigation and space exploration will need to be up to 10 or 100 times larger than the largest antenna presently in space while maintaining surface tolerances in the order of millimeters. More specifically, an antenna used as the collecting element for a full-time, high resolution coastal zone monitor is envisioned to consist of a 300 meter diameter reflector located 500 meters away from a 100 meter long feed array. This system is a promising method to obtain an all-weather, day-night surface feature mapping capability with better than 1km spatial resolution - a capability required for understanding and managing the valuable but fragile coastal zone portion of our environment.

WHAT IS LSST?

The Large Space Systems Technology (LSST) Program was organized by NASA in 1977. It is part of the 524 Systems Technology Program, managed by the Materials and Structures Division, Code RW, Office of Aeronautics and Space Technology (OAST), NASA Headquarters. OAST has delegated management responsibility for LSST to the Langley Research Center (LaRC) which will function as the Lead Center. The Director, LaRC, has organized the LSST Program Office (LSSTPO) which will manage the program. The following NASA organizations will participate in the program: (Organizational Chart Figure 3)

- Goddard Space Flight Center (GSFC)
- Jet Propulsion Laboratory (JPL)
- Johnson Space Center (JSC)
- Langley Research Center (LaRC)
- Marshall Space Flight Center (MSFC)

The technical objective of the LSST Program is to provide advanced technology in structural concepts and in areas closely coupled with structures including electronics, control systems, analyses, materials, joining, and assembly procedures in order to evolve cost effective large space systems. The management objective of the program is the utilization of the strengths of each participating NASA Center in its technology areas of expertise, and to provide and disseminate the technical results in a timely and cost effective manner.

The objectives of the LSST Program will be met through three major thrusts. These thrusts can be generally categorized as follows: (1) Discipline oriented research and technology development in the participating NASA Center line organizations with emphasis on innovative concepts and design method development; (2) A comprehensive ground test program supplemented by small flight experiments to provide the high level of confidence necessary for maximum utilization of the newly developed technology; and (3) The timely dissemination of new technology developments to potential users to permit maximum utilization of the information in the early stages of planned missions.

WHEN LSST?

The development of advanced technology, to the point of readiness for application, is on the order of 6 to 10 years. With the goal of the LSST Program to provide developed and verified large area space systems technology for missions beginning in 1985 (with earlier "spin-offs" requested), it was important to start the program in FY 79.

Early implementation of the LSST Program to start the development of advanced technology for large area space systems on an integrated basis is both efficient and cost effective. The outputs of this program will not only benefit the civilian space program but will have applications to DOD programs that require the utilization of large space systems in the same time period.

HOW WILL LSST BE IMPLEMENTED?

The LSST approach is keyed to a centrally managed, multi-center management approach which provides the opportunity to work across the multi-disciplines and to match the roles and missions (expertise) of NASA Centers. Initial technical tasks for LSST were identified through a process of evaluating proposed future large space missions to select those systems as foci which will provide the greatest benefits to the nation and NASA based both on technical and cost benefit considerations.
Additional technical tasks will be derived and prioritized by studying these foci systems in greater depth.

If LSST is to be of benefit to large space systems planned for new starts in the next 5 to 10 years, it is important that it provide methods for timely dissemination of technical results to potential users in the government and industry. This will be done via a special LSST data dissemination plan which is being generated at Langley. This plan will also make provisions for the rapid distribution of technical results from LSST related activities performed in the R&T base at the various centers.

The approach to the development of technology in all areas is similar. Investigations will be conducted to define candidate concepts appropriate for each application. Initially, several concepts and techniques will be investigated by means of analyses and ground testing. Following these investigations, engineering studies, feasibility tests, and/or pilot models will be used to select and develop the most promising concepts. Finally, the developed technology will be integrated to define baseline structures, construct large test models, demonstrate proof of concept, and scope the applicability of the structural system. Every effort will be made to conduct technology experiments in ground facilities. However, for cases where ground simulation of the space environment is inadequate, flight experiments may be performed.

Note that "systems," as applied to the LSST Program, is not really a technology area, but serves to continually focus and integrate the eight selected areas of technology. Also note that each of these areas is divided into activities which in turn are broken into specific tasks and milestones.

Systems

The Systems Area plays a vital role in the LSST Program. The objective of the activities in this area is to assure that all technologies being developed by the LSST Program are properly focused and integrated throughout the life of the program.

Studies will be performed to identify the large space systems required to achieve national and NASA goals along with technology development requirements. In many cases, LSST funded studies will augment on-going systems studies at each NASA Center to identify technology needs for future missions, for integrating and continually updating and evaluating the technology being developed in all areas of the program. Economic and scientific benefits will be an important consideration in the selection of LSST focus missions. Large space systems capable of executing focus missions will be selected and definitized to the point where requirements for technology developments are ascertained.

Analysis and Integrated Design

New analysis tools are needed to evaluate the performance, response, and structural loads and stresses of large flexible platforms and reflectors. These analysis tools are discussed below.

Large area space structures will be designed to withstand loads imposed by Shuttle transportation, systems operations, and the space environment. In the zero-G space environment, these loads are extremely low. Consequently, the full scale structure might not withstand the ground test environment. To design such structures for the ground environment would be prohibitive in terms of material and launch costs. To test the prototype full scale structures either in a simulated environment or in orbit would not be practical. Therefore, it is necessary to develop accurate mathematical models and scaling algorithms so that design margins and the resulting structural mass may be held to acceptable limits.

Methods for the efficient prediction of electromagnetic properties of large reflectors will be obtained by the development of cost effective electromagnetic field prediction analyses for scanning type antennas and multibeam continuous surface reflector type antennas. The tools needed for the design of appropriate control systems will be obtained through development of analysis techniques for maximum performance through placement of sensors and actuators and synthesis techniques of control laws and structural characterisation. Advanced analytical tools will also be developed for the prediction of structural loads and distortions. Because of serious thermal problems, advanced control concepts must be developed. To provide the necessary structural dynamic analysis and testing tools, accurate and efficient modeling procedures coupled with optimization analyses will be developed to determine the structural dynamic characteristics of flexible, very large structures and their interaction with the control system. Ultimately, these newly developed analytical tools will be assembled and integrated into a total system design code. The resulting computer code will reduce the preliminary design turn-around time such that designers of future large area space systems can make proper trade-off studies in a cost effective manner.
Structural Concepts—Deployable Platform

The thrust of this technology area is to define, develop, and evaluate low mass structural concepts that can be fabricated, assembled, and automatically deployed into space into a structure much larger than 100 meters using deployable modules, methods of coupling deployed modules will be investigated.

Structural Concepts—Deployable Reflectors

The principal target of this technology area is to define, develop and evaluate low mass reflector concepts that can be fabricated, assembled, and automatically deployed into shaped surfaces 30 to 300 meters in size with rms surface accuracies consistent with the foci of the LSST Program. The majority of the activities in this area are similar to those in the Deployable Platform Technology Area, i.e., concepts, analyses, development, and dynamic deployment tests. Two activities are new. Because of the high surface accuracies required for many of the applications of large space systems, some form of active surface control is necessary. Consequently, methods must be developed to measure the shape of the surface and appropriate mechanisms designed to change the surface to the required shape. Techniques will be investigated to precisely measure distances between points on a surface, surface shape or flatness, and the locations of points in space. In addition, studies will be performed to determine the surface accuracies achievable with various deployable concepts and efficient methods of altering the shapes of their surfaces.

Control Systems

Work in the Control Systems area will provide the technology required to design, fabricate, and evaluate three kinds of control systems: shape, attitude, and orbit stationkeeping.

To provide the surface accuracies required for some of the missions using reflectors, control systems capable of maintaining surface shapes within a range of 1-10 mm, must be developed and verified. To provide the necessary pointing control in the range of 0.01 of a degree for large flexible systems, new concepts using distributed sensors and actuators will be investigated. Once appropriate analyses are developed and trade-off studies completed, control optimization techniques will be defined and evaluated.

Because of the large size, low mass, and relative low stiffness of future large space structures, new control concepts may be needed for orbital transfer and stationkeeping. The orbital transfer and stationkeeping requirements will be established and appropriate analytical tools developed. Trade-off studies will then be made on both new and
existing control technology concepts and the most appropriate systems selected. Mechanization of the system and experimental verification will follow.

Electronics

The technology that is essential for the operation and subsequent evaluation of both passive and actively controlled systems will be developed in the Electronics Area and is discussed below.

Electrical subsystems will be used for active surface control as well as in providing housekeeping data that must be used in verifying system performance. Therefore, techniques will be developed for signal conditioning, data acquisition, and data transfer.

Power, in various forms, must be distributed throughout a large space system. Both centralized and distributed power systems will be evaluated and trade-off studies conducted. In addition, studies and tests will be performed to determine the feasibility of using the structure itself as a conductor for distributing power, thereby reducing the mass of the overall system. System requirements for these concepts will be defined through appropriate LSST System Studies.

Techniques will be investigated that will reduce data channel interference and multipaction effects. Such interference could severely degrade the data handling capacity of the instrumentation subsystem on board the large space system. Methods will be devised for improving radio frequency connections, and components will be developed that have surface finishes that will reduce multipaction effects generated in high power systems.

Advanced Materials and Joining

The high initial cost of large space systems necessitates a requirement of a long operational lifetime. At the present time, a 30 year lifetime is being considered. To accomplish this objective, activities in several critical areas will be undertaken. Accelerated laboratory testing procedures and associated analyses will be developed to predict lifetime of both metals and composites in the 30 year range. Long life, dimensionally stable polymeric matrix composites will be developed. If necessary, metal and glass matrix composites will be developed. Thin gauge, low mass structural alloys will also be investigated. To solve some of the serious thermal problems, advanced thermal control concepts such as integral control surface and heat pipes technology will be examined.

Space environmental effects will be evaluated for both low and geosynchronous orbits. Special characteristics of materials, such as outgassing, electrical conductivity, space charge relief, and radiation resistance, will be evaluated. As the performance of the assembled structure depends to a large extent on the integrity of the joint, techniques for joining of the candidate materials must be devised and evaluated for reliability and long life.

Space Fabrication

The applicability and cost effectiveness of using space fabrication techniques for building large platforms in the foci missions will be the subject of system studies in the initial phase of the program. Space fabrication techniques involve fabrication and assembly of structural members from densely packaged, pre-processed material. Machines fabricating continuous light weight trusses such as the concept illustrated in Figure 4 may become a valuable tool in construction of many of the large space systems. Structural concepts, materials, and equipment technology needs for space fabrication will be an integral part of the LSST Program.

A FUTURE LARGE SPACE SYSTEM

"A Quick Look at Solar Power Satellite"

Perhaps the most fascinating of the large space systems is the concept of a Solar Power Satellite (SPS) (Figure 5). Collection of meaningful quantities of energy from the Sun involves a vast area of collector in geosynchronous orbit, long transmission lines and a huge phased array antenna for transmission of the power to the station on the ground. JSC has been conducting both in-house and contracted studies of the SPS which has begun to outline areas of technology which will be necessary for such a glamorous majestic and utilitarian program. For the SPS concept, insights into approaches to other large space systems are exposed which might not be apparent with stepwise increase in technology such as going from a ten meter to a hundred meter antenna.

As the SPS has been studied, several interesting approaches have evolved. Initially, there was an emphasis on very efficient lightweight structure. As it became apparent that structure was not a significant percentage of the system mass, concern shifted to concepts which could be more easily constructed (Figure 6). These concepts compromised structural efficiency in order to achieve rapid erection and a high density packaging for the materials during the launch operation. Of course,
the payload density has a profound effect on the design of the launch vehicle. Small influences become particularly significant when launching a million pounds a day in a recoverable booster system which is a typical scenario for the SPS program. Typical packaging densities are shown in Figure 7.

Studies of construction of an SPS show a diversity of concepts. One of the study issues is location of construction. The principal driver in such trades is the use of self generated power to operate a high specific impulse propulsion system for the transfer from LEO to GEO (Figure 8). Construction support is easier in LEO, but the environment is more severe with day-night cycles, higher gravity gradient torques, potential collisions, and exposure to the radiation belts during transit affecting solar cell performance. Also part of the trade is the long transit time of a completed structure which is manifested as a capital cost. Construction of large modules in LEO requires assembly of the modules in GEO. Schemes as shown in Figure 9 are needed to berth the modules and to make final attachment of modules in completing the satellite.

The construction base (Figure 10) is generally conceived as an open space frame to provide a reference and support system for the construction operations such as fabrication of the primary structure, attachment of solar cell blankets in membrane fashion to the structure, deployment, and connection of the power distribution system (Figure 11). Even though the construction of the satellite may be highly automated, building of the construction base is more likely to be done with individual erection and deployment operations.

Construction of an SPS power transmission antenna is a unique challenge (Figure 12). The phased array is made up of smaller subarrays which are sized by the trade of mechanical pointing accuracy and the desire for a minimum number of subarrays to be controlled by the phase control system. Pointing of the antenna is accomplished at the first level by mechanical pointing of the entire antenna. Individual subarrays are aligned to this reference during construction. Electronic manipulation of the phase relationship between subarrays accomplishes final pointing to the target rectenna.

The effective density of waveguides for the antenna is very low in the operational configuration. Packaging for launch represents a severe penalty on effective payload density (Figure 14). Yet the tolerance requirements on the finished are so close that it is difficult to conceive of a technique for increasing packaging density.

Technology Needs for SPS

The SPS presents a number of technological challenges, many of which can be solved by a well focused technology program such as LSST. It is not particularly necessary that SPS be used as a specific focus because many of the technology needs parallel those with more immediate potential. For example, material composites using graphite fibers to achieve very low coefficient of thermal expansion can reduce the impact of thermal structural interaction on maintaining stringent shape limits. With this capability to reduce thermal effects, the need for thermal-structural analysis capability may actually be increased.

Operational lifetimes of 30 years or more create a technical burden to demonstrate or predict materials behavior. Methods to accelerate space environmental testing will be required to make accurate predictions.

A broad range of assembly techniques will be needed ranging from individual extravehicular activity through manned remote work stations and large space cranes. Systems trades for application of various techniques will be strongly influenced by timeline limitations. Technology development must provide a basis for prediction of times for performance of operations and the effect of repetitive activity.

Another capability which must be initiated in the space shuttle era and extended to SPS construction is the berthing of very large modules. The docking techniques prevalent in Gemini and Apollo where relative motion between vehicles was absorbed by impact attenuation must give way to more sophisticated berthing type operations. In berthing, relative motion would be nulled out prior to contact, then using devices such as a manipulator, the cumbersome, fragile structures would be drawn together under well controlled conditions.

CONCLUSIONS

The variety of technology needs recognized for SPS are reflected in many other future systems being studied for utilization of the space shuttle. The challenge of the LSST Program will be to recognize and integrate a broad spectrum of common technology requirements. Often technology is developed too late to support specific program requirements or has not recognized the true payoff technology areas. From the LSST planning efforts of the past few months, it can definitely be concluded that many large area space systems will be required in the 1985-2000 time
period, and that much of the technology required for these systems does not exist today. LSST will provide NASA with the advanced technology necessary to achieve cost effective systems designs for a multitude of future missions. It will provide a systematic approach to technology development and place its resources in the areas of greatest need. The LSST inter-center approach which matches Center "Roles and Missions" to technology needs, places the expertise and interest where it can be most effective from both technical and costs standpoints.

Figure 1

Figure 2
Figure 3

LSST PROGRAM
BEAM FABRICATION EXPERIMENT

DEMONSTRATE
- MACHINE PROCESSES IN SPACE ENVIRONMENT
- OPERATIONAL INTERFACES WITH ORBITER
- BEAM THERMAL CHARACTERISTICS
- BEAM DYNAMIC PROPERTIES

Figure 4

A Typical SPS Configuration
(2 x 5000 Megawatts Output)
SPS REFERENCE CONFIGURATION

256 BAYS
660 x 660 m

Figure 6

COMPONENT PACKAGING CHARACTERISTICS

ANTENNA SUB ARRAY
- MIN = 12 KG/m³
- MEDIAN = 28 KG/m³
- MAX = 89 KG/m³
- 13,874 UNITS

SATELLITE STRUCTURE
- 104 KG/m³
- 1,980 UNITS

DC-DC CONVERTER
- 920 KG/m³
- 384 UNITS

SECONDARY STRUCTURE
- 77 KG/m³
- 122 UNITS

NOTE: PACKAGING WITHIN PAYLOAD SHROUD TENDS TO REDUCE COMPONENT DENSITY

Figure 7

LEO CONSTRUCTION CONCEPT

1. DEPLOY SOLAR ARRAY
2. DOCK MODULES
3. SELF POWERED TRANSPORT TO GEO (180 DAYS)
4. ROTATE ANTENNA INTO POSITION (MODULES 4 AND 8)
5. CONSTRUCT 8 MODULES AND 2 ANTENNAS
6. DEPLOY PORTION SOLAR ARRAY
7. GEO CONSTRUCTION BASE
8. GEO FINAL ASSEMBLY BASE
9. DEPLOY SOLAR ARRAY GEO FINAL ASSEMBLY BASE

Figure 8
Figure 9

GEO BERTHING CONCEPT

Figure 10

LEO CONSTRUCTION BASE

Figure 11

SOLAR ARRAY ARRANGEMENT AND ATTACHMENT
ANTENNA PRIMARY STRUCTURE

- GRAPHITE COMPOSITE
- TETRAHEDRAL PLANAR TRUSS

SECTION A-A

Figure 12

MICROWAVE POWER TRANSMITTER DESIGN CONCEPT

Figure 13

TYPICAL COMPONENT MIXING

Figure 14