# LARGE SPACE SYSTEMS TECHNOLOGY PROGRAM

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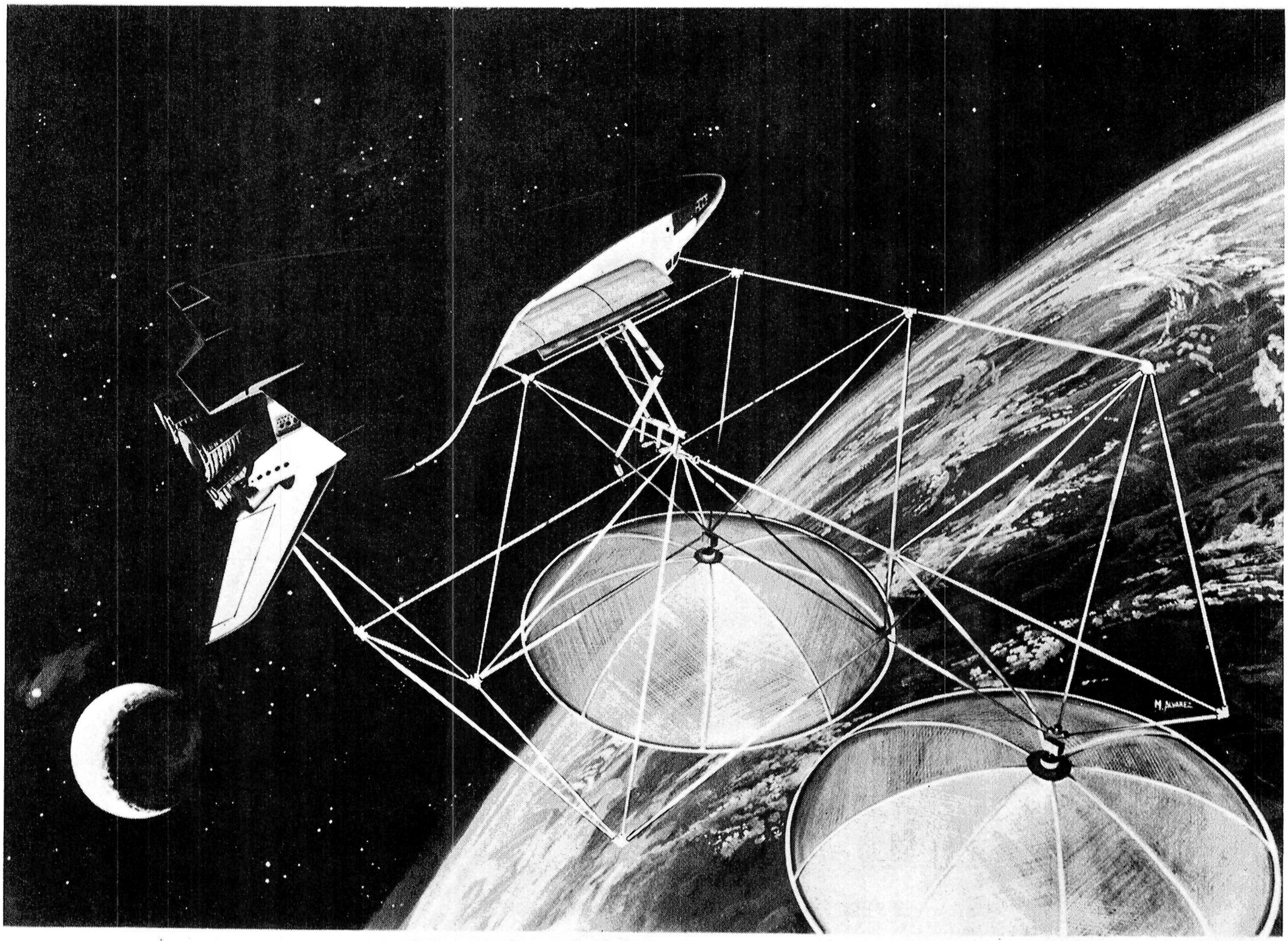
TECHNOLOGY



FOR LARGE SPACE SYSTEMS

In order to provide the capability to design and operate large space systems in the shuttle-era, specific technical challenges must be met as shown on this visual. First, space-configured spacecraft designs must be conceived and developed. Specifically, system designs must be developed which satisfy operational performance requirements and tolerate operational loads. Low environmental and operational loads will lead to lightweight systems. Advanced control systems will be needed to maintain the required attitude and shape control of these lightweight systems.

Secondly, the design and operational requirements of these "large space systems" must be compatible with space shuttle capabilities and limitations. Consequently, the designs must be packageable and assembleable. The packaged system must tolerate the shuttle cargo bay launch environment. Assembly operations must be compatible with capabilities of the shuttle remote manipulator subsystem, the crew, and additional tools and construction aids.

Finally, the overall design of shuttle-era large space systems must be cost effective from the viewpoint of the total mission. Specifically, the packing density must be high. Assembly complexity must be minimized. Selected concepts and techniques should support minimum overall mission cost. For example, while assembly costs may be minimized through the use of deployable elements, the cost of design, fabrication, and testing of these structures might far exceed similar cost elements for erectable concepts. The reliability of on-orbit deployment and/or assembly, and the reliability of the assembled spacecraft will impact overall mission cost and must be considered. Extending the life of components and systems will reduce overall mission costs by reducing the required maintenance and replacement operations. The success in reducing overall mission cost will be a primary factor in the eventual decision to proceed with the development of operational large space systems.

# TECHNICAL CHALLENGES OF SHUTTLE-ERA LARGE SPACE SYSTEMS

- THE DEVELOPMENT OF "SPACE - CONFIGURED" SPACECRAFT CONCEPTS
  - DESIGNED TO MEET PERFORMANCE REQUIREMENTS
    - LARGE
    - PRECISION SHAPE
  - DESIGNED FOR THE OPERATIONAL ENVIRONMENT
    - LIGHTWEIGHT
    - ADVANCED CONTROL
- COMPATIBILITY WITH THE SPACE TRANSPORTATION SYSTEM
  - CAPABLE OF BEING PACKAGED WITHIN THE SHUTTLE CARGO BAY
  - CAPABLE OF BEING ASSEMBLED BY THE SHUTTLE WITH TOOLS AND AIDS
- COST EFFECTIVENESS
  - COST - EFFECTIVE PACKAGED VOLUME/WEIGHT
  - COST - EFFECTIVE DEPLOYMENT/ASSEMBLY/CONSTRUCTION TECHNIQUE
  - OVERALL COST EFFECTIVENESS (DESIGN/FABRICATION/TEST/ON-ORBIT ASSEMBLY/OPERATIONS)
  - HIGH RELIABILITY (CONSTRUCTION AND OPERATIONS)
  - LONG-LIFE

In order to provide a base of systems technology to enable this new class of spacecraft, the NASA Office of Aeronautics and Space Technology (OAST) established the Large Space Systems Technology (LSST) Program. The multi-Center LSST Program is managed by the NASA Langley Research Center (LaRC). The program is developing fundamental systems technology which will provide a basis for the design of large shuttle-era spacecraft. Ongoing and planned activities will ensure that important initial design choices are made on a sound basis of technical knowledge and experience.

# THE LSST PROGRAM

OBJECTIVE:

TO DEVELOP TECHNOLOGY TO ENABLE AND ENHANCE SHUTTLE - COMPATIBLE LARGE SPACE SYSTEMS

- SPONSORING PROGRAM OFFICE:

  OFFICE OF AERONAUTICS AND SPACE TECHNOLOGY (OAST)

- LEAD CENTER AND PROGRAM MANAGEMENT OFFICE:

  LANGLEY RESEARCH CENTER
  LARGE SPACE SYSTEMS TECHNOLOGY (LSST) PROGRAM OFFICE

- PARTICIPATING NASA CENTERS:

  GODDARD SPACE FLIGHT CENTER
  JET PROPULSION LABORATORY
  JOHNSON SPACE CENTER
  LANGLEY RESEARCH CENTER
  LEWIS RESEARCH CENTER
  MARSHALL SPACE FLIGHT CENTER

For the past several years, OAST has periodically surveyed the NASA program offices to identify future space missions which will require large space systems. The results of the most recent survey are shown here. This mission model includes potential missions derived from many sources. Individual missions cover a wide spectrum in level of definition and program office support. However, the compilation gives an overall indication of the strong potential requirements for this class of space vehicle.

## POTENTIAL LARGE SPACE SYSTEMS MISSIONS

| | | 1980 | 1985 | 1990 | 1995 | 2000 |
|---|---|---|---|---|---|---|
| **HIGH STIFFNESS TRUSS STRUCTURES** | MULTIPURPOSE PLATFORMS | | SCIENCE APPLICATIONS LEO 30M | COMM/ OBSER. GEO 50M | COMM./ OBSERVATIONS GEO 100M | |
| | FACILITIES | | MATERIALS EXPERIMENTATION CARRIER 10–30M | SPACE OPERATIONS CENTER 100M | | |
| **LOW STIFFNESS PLANAR SUB STRUCTURES** | POWER MODULES | | 25 KW (20x20M) | | 250 KW 100x50M | |
| | ENERGY SATELLITES | | | ← — — — | SPS TEST ARTICLE SUBSCALE | — — — — → |
| **PRECISION/SHAPED SURFACE STRUCTURES** | HIGH ENERGY ASTRONOMY | | | SOLAR X-RAY PINHOLE CAMERA 100M | X-RAY OBSERVATORY 75M DIA. | |
| | SUBMILLIMETER, IR, AND OPTICAL ASTRONOMY | | | IR SUBMILLIMETER 15M | LINEAR OPTICAL ARRAY 20M | OPTICAL ARRAY 100MD |
| | RADIO ASTRONOMY | | | VLBI 5GHz 15M | VLBI 20 GHz 30M | RADIO TELESCOPE 1KMD |
| | PLASMA PHYSICS | | WAVE INJECTION WIRE LEO 200M LONG | WAVE INJECTION WIRE GEO 2KM LONG | | |
| | DEEP SPACE NETWORK | | | ORBITAL RELAY ANTENNA 30M AT 30GHz OR 300M AT 3GHz | | |
| | COMMUNICATIONS | | MOBILE 800MHZ 60MD | SWITCHED TRUNKING 6 & 14 GHz 15MD | ADVANCED APPLICATIONS 1–14GHz 100MD | |
| | REMOTE SENSING | | SOIL MOISTURE 10 x 10M PASSIVE 05 x 10M ACTIVE | SOIL MOISTURE ACTIVE 10 GHz 30 MD | SOIL MOISTURE PASSIVE 7GHz 100M | STORMCELL TRACKING ACTIVE 100MD |
| | OTHER | | | NIGHT ILLUMINATOR REFLECTOR 100–300M DIA. | GRAVITY WAVE INTERFEROMETER 1–10 KM LONG | |

The identified potential missions fall primarily in two classes: large antennas and platforms. In order to provide an integrating focus to the technology development, the LSST Program has selected a set of reference missions which collectively represent the technology challenges. These missions are studied to define technology requirements and to identify subsystem interfaces.

# REFERENCE MISSIONS OF THE LSST PROGRAM

- LARGE ANTENNAS
    - MOBILE COMMUNICATIONS
        - 60 - 100 M (180 - 300 FT)
        - 0.8 - 14.0 GHz ( λ /20 SURFACE ACCURACY)
    - VERY LONG BASELINE INTERFEROMETER (VLBI)
        - 40 - 80 M (120 - 240 FT)
        - 1.4 - 14.0 GHz ( λ /10 SURFACE ACCURACY)
    - ORBITING DEEP SPACE RELAY STATION (ODSRS)
        - 20 - 50 M (60 - 150 FT)
        - 3.0 - 30.0 GHz ( λ /30 SURFACE ACCURACY)
    - RADIOMETERS
        - 30 - 100 M (90 - 300 FT)
        - 1.4 - 10.0 GHz ( λ /50 SURFACE ACCURACY)
- PLATFORMS
    - ADVANCED SCIENCE/APPLICATIONS PLATFORM
    - OPERATIONAL GEOSYNCHRONOUS COMMUNICATIONS/OBSERVATIONS PLATFORM
    - SATELLITE POWER SYSTEM (SPS) ENGINEERING TEST ARTICLE
    - SPACE OPERATIONS CENTER (SOC)

The LSST Program is currently subdivided into the elements shown. These elements comprise the primary technology needs of near-term shuttle-era large space structural systems. Included are the structural systems and related technologies. Program activities are also undertaken to define the interfaces of the other subsystems to the structure.

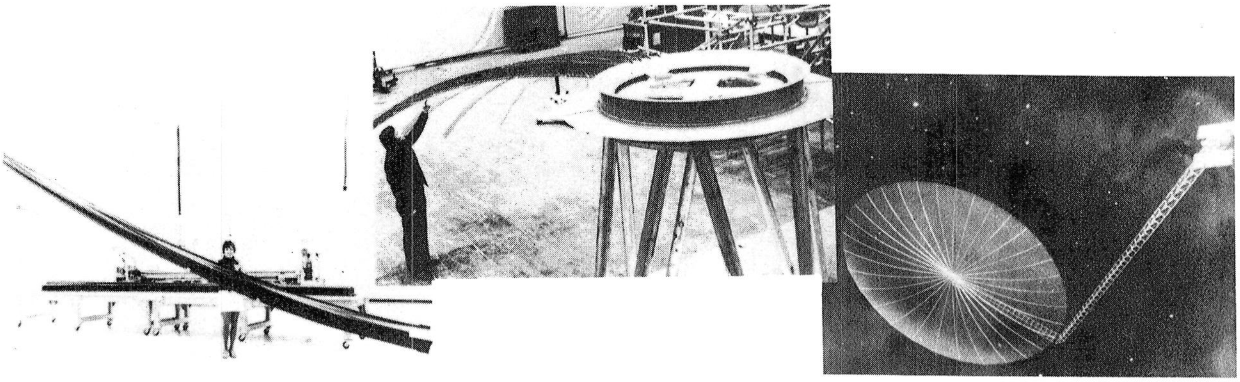
## ELEMENTS OF THE LSST PROGRAM

- PROGRAM PLANNING, INTEGRATION AND MANAGEMENT
  - PROGRAM MANAGEMENT
  - SYSTEM REQUIREMENTS AND INTERFACE DEFINITION
  - FLIGHT EXPERIMENT DEFINITION
- ANTENNAS
  - MAYPOLE (HOOP/COLUMN) CONCEPT DEVELOPMENT
  - OFFSET WRAP-RIB CONCEPT DEVELOPMENT
  - ELECTROMAGNETIC ANALYSIS
- SPACE PLATFORMS
  - DEPLOYABLE SYSTEMS
  - ASSEMBLY METHODS
  - MODULAR CONTROL SYSTEMS
- ASSEMBLY EQUIPMENT AND DEVICES
  - LARGE PLATFORM ASSEMBLER TECHNOLOGY
  - ASSEMBLY AND CONSTRUCTION EQUIPMENT
- SURFACE SENSORS AND CONTROL
  - STRUCTURAL MEASUREMENT SYSTEMS
  - ELECTROSTATIC SHAPE CONTROL
  - ACTIVE SHAPE AND ALIGNMENT SENSOR AND ACTUATOR CONCEPTS
- CONTROL AND STABILIZATION
  - LARGE SPACE SYSTEMS CONTROL
- ANALYSIS AND DESIGN SYSTEMS
  - INTEGRATED ANALYSIS AND DESIGN

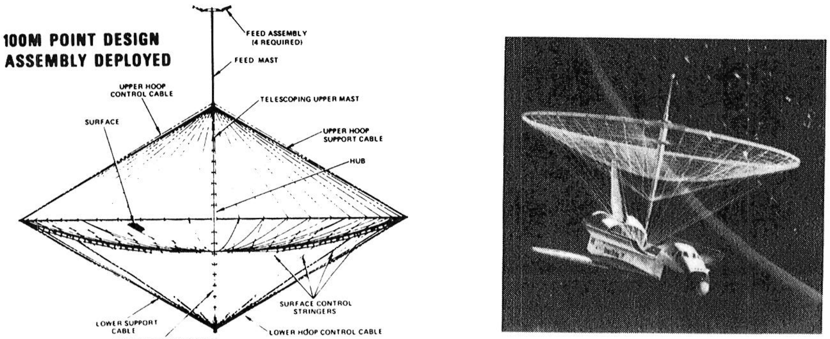
The LSST antenna technology program has as its objective the development of the antenna technology required to support the large antenna reference missions.

The offset wrap-rib antenna concept development activity will develop antenna technology for classes of applications which require large unblocked apertures of up to 1000 feet (300 m). Development activities will include definitization of the antenna design (surface quality, weight, deployable feed support structure), definition of scaling laws, development of structural and thermal analysis techniques, characterization of surface adjustment techniques, development of a feed support structure, the development and evaluation of critical components, and the development of cost and performance models. At the present time, design requirements have been determined and the reflector configuration optimized. Currently, the feed support structure is being optimized, and surface adjustment techniques are under evaluation. In the near future, fabrication of critical components for a 180 foot (55 m) model will be initiated.

# THE TECHNOLOGY FOR LARGE ANTENNAS



**OFFSET WRAP-RIB CONCEPT**

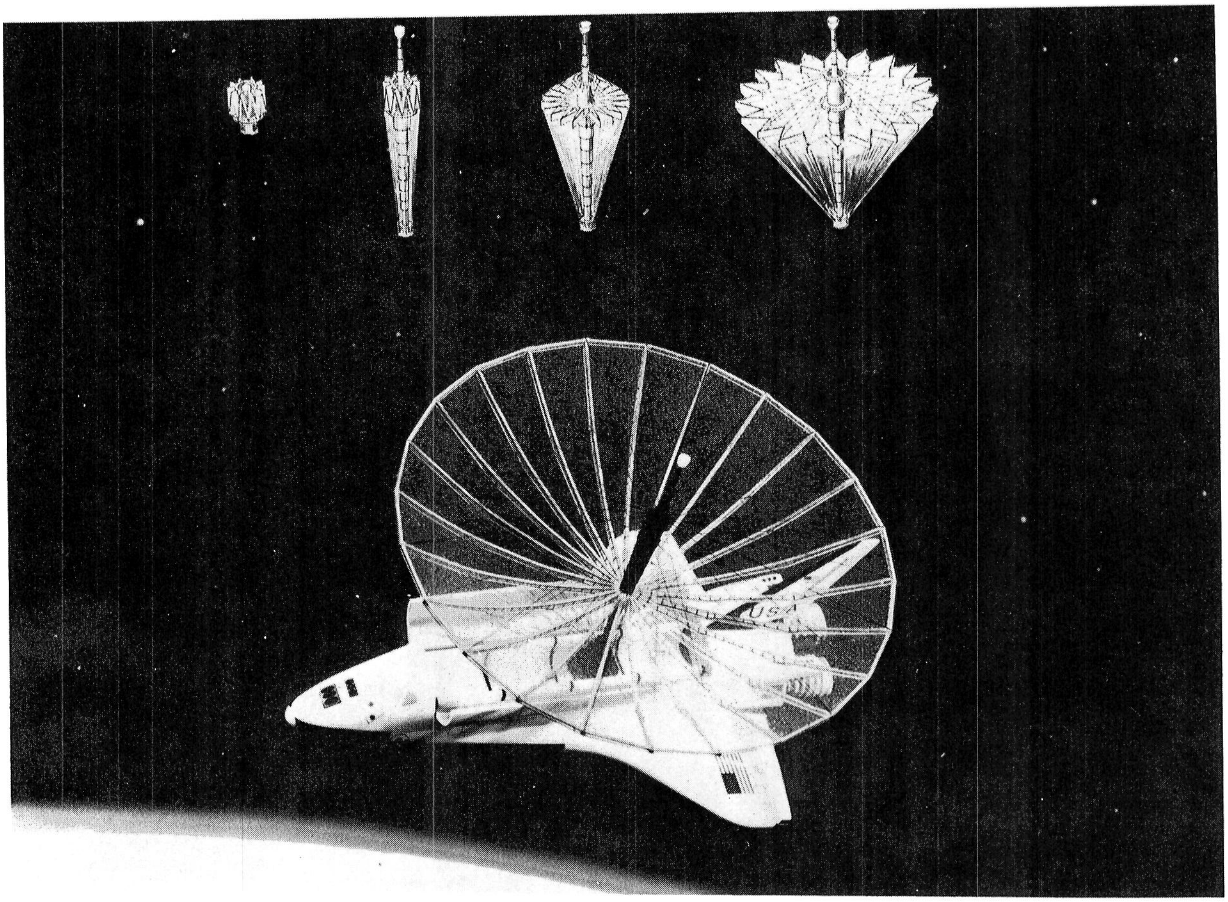


**MAYPOLE (HOOP/COLUMN) CONCEPT**

The objective of the **Maypole** (hoop-column) antenna concept development is to structurally characterize this antenna concept and to determine its performance through tests and analyses. Primary activities are to determine surface quality as a function of size, to develop structural and thermal analysis techniques, to define the dynamic behavior of the antenna during deployment, and to define ground-test requirements. In addition, the activity will define and evaluate surface adjustment techniques, define scaling laws, and develop cost models. Currently, the antenna configuration has been defined, and a point design of a 300-foot (100-m) antenna is nearing completion. The end product is expected to be a data base which will permit estimates of performance and cost for Maypole (hoop/column) antennas up to 1000 feet (300 m) in diameter.

Also, included in the antenna technology program is the development of analysis techniques for predicting electromagnetic performance of a broad class of large reflectors. These techniques will show specific effects of surface errors and distortions and their correlation and distribution on antenna performance.

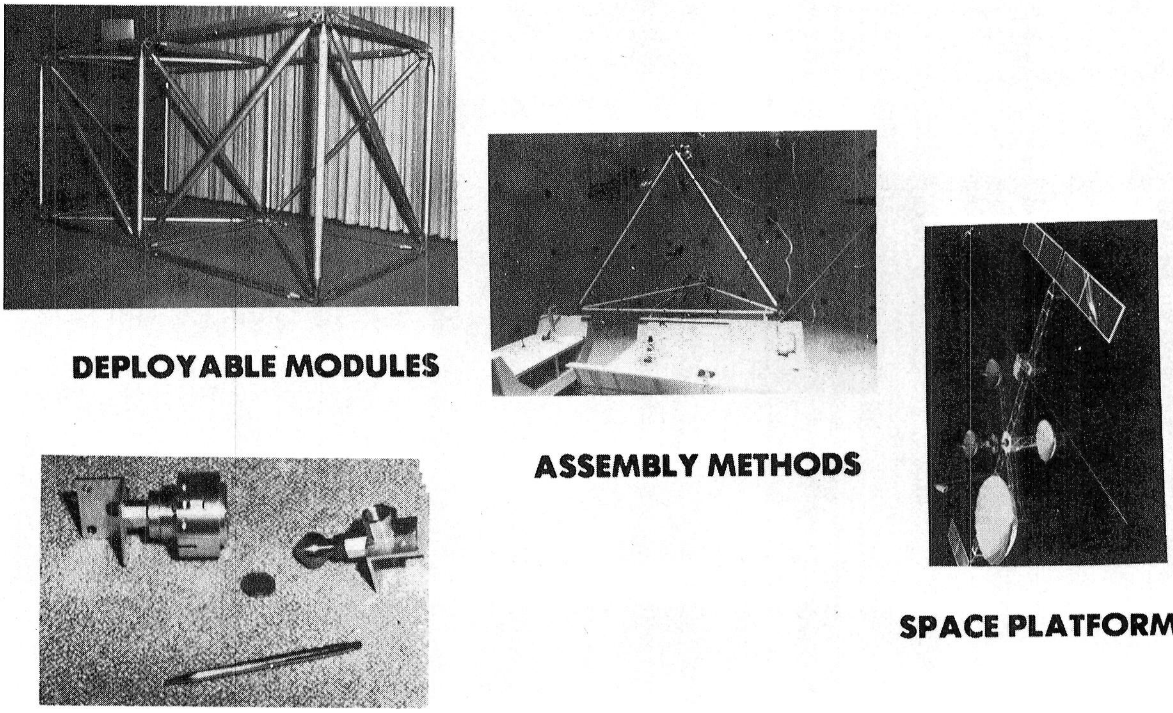
## DEPLOYABLE ANTENNA



An important class of structural concepts are the deployable trusses. This structural concept is attractive for space construction because major subassemblies can be completely fabricated and functionally checked out on the ground. The deployable concept is also attractive in that it minimizes the time required for on-orbit construction and checkout. However, deployable structural concepts present designers with a number of difficult technical challenges. Compared to other concepts, deployable structures have a low packaging efficiency. Therefore, optimum folding concepts must be developed. The joint concept has a critical impact on reliability of the deployment process. The degree of joint rigidization following deployment can strongly effect the structural dynamic behavior. The overall reliability of the system depends on the development of reliable deployment concepts and mechanisms. Prediction of deployment dynamics requires the development of new models and test data for validation. Finally, the structural concept must be functionally useful. Therefore, as the concepts are developed, it will be necessary to include provisions for utility distribution and subsystem integration.

The overall objective of the space platform element of the LSST Program is to develop the technology needed to design, fabricate, package, and automatically deploy structurally efficient linear or area platform structures. Specific activities will include the concept definition of several alternative deployable modules. The mechanisms necessary for the implementation of the concepts will be designed, fabricated, and tested. Currently, a double-fold concept has been designed and partially tested. Full-scale module-to-module couplings have been designed and tested. A 1/2-scale model of the deployable module has been fabricated and tested. Three full-scale 18-foot (5-m) modules are under fabrication for use in deployment and assembly tests. The modules have been designed to accommodate assembly test in a neutral buoyancy facility.

## THE TECHNOLOGY FOR LARGE SPACE PLATFORMS



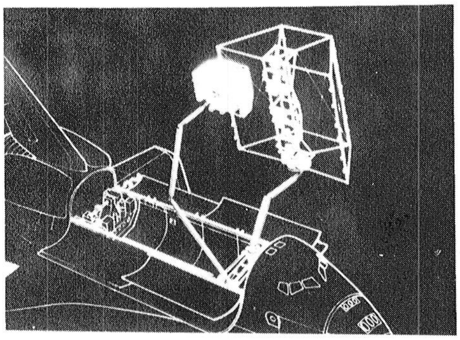
The potential ability of the space shuttle to assist in the on-orbit assembly of packaged spacecraft is a fundamental consideration in development of this new class of spacecraft. The LSST Program is conducting activities which will develop and evaluate efficient packaging and assembly techniques. The planned tasks will consider assembly techniques ranging from manual to fully automated. Analyses and simulations will be performed to define the capabilities and limitations of the various techniques. The experimental results will provide data on which to base the selection and development of cost-effective assembly techniques.

Primary initial tests have addressed the capabilities and limitations of extravehicular activity (EVA) for assembly operations (previous graphic). Of the various techniques, EVA is considered to be a base of reference. This technique is the only method on which any space experience exists. Assembly by EVA is shown to be very time-consuming and relatively inefficient. However, EVA assist may be very effective for specific operations. In fact, on the basis of past space experience, some operations may not be possible without EVA assist.

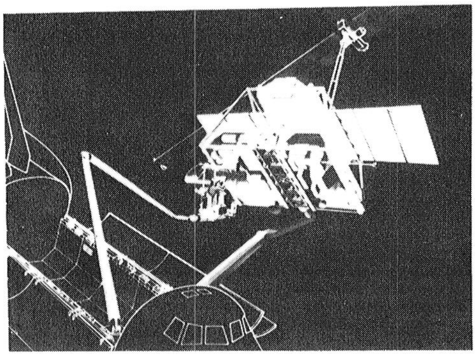
A comprehensive series of assembly tests are currently underway in the Neutral Buoyancy Facility at the Marshall Space Flight Center. This facility includes a cylindrical water tank with a depth of 40 feet (12 m). Tests conducted in the tank simulate operations in zero gravity. The objectives of current experimental testing are to develop manual assembly techniques, identify fundamental requirements for multipurpose assembly aids, evaluate various techniques for the assembly of elements and subassemblies, define assembly time lines for the various techniques, and identify fundamental limitations of this assembly method. Testing has included the manual connection of an electrical connector designed for quick assembly, assembly of a tetrahedral cell with various member lengths and joint concepts, and the attachment of a simulated equipment or subsystems module. Extensive testing was performed on the assembly of the tetrahedral cell. Experimental tests were performed using 30-foot (9-m) and 18-foot (5-m) strut lengths, using both the snap-lock and ball-and-socket joint concepts. These tests have shown the feasibility of manual assembly. They have also demonstrated the critical importance of joint design and the need for basic assembly aids.

Machine-aided assembly techniques appear to offer many advantages. The concepts offer the potential for automation which could significantly reduce assembly time. Activities planned within the LSST Program will develop concepts for RMS-aided assembly techniques and define the requirements for special end-effectors and assembly aids. Assembly concepts will be evaluated to experimentally define time lines and fundamental limitations of the approach. Automated assembly of space structures is an advanced concept which may be the only practical approach for the assembly of very large systems.

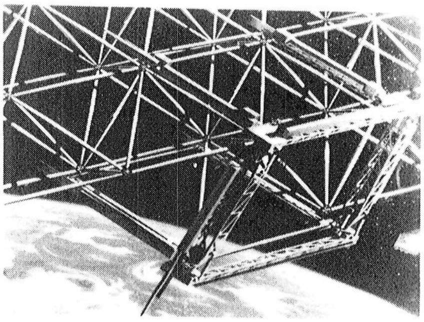
## ASSEMBLY TECHNOLOGY



ASSEMBLY AND CONSTRUCTION EQUIPMENT



AUTOMATED ASSEMBLY



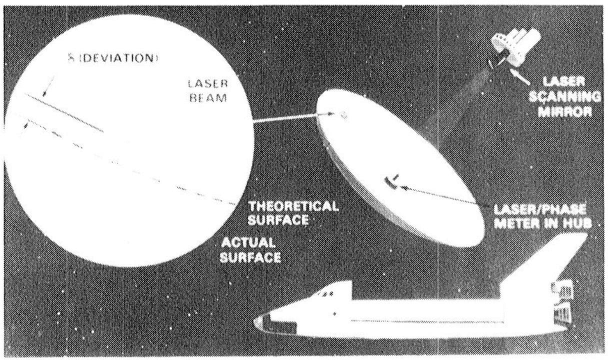
Large systems in space will require an ability to precisely determine and statically control surface contours. Two surface measurement systems are currently under test and evaluation for application to large antenna concepts. Evaluations of breadboard units will be completed this year. The design objective is a surface measurement precision of 0.1 mm at a distance of 500 feet (150 m).

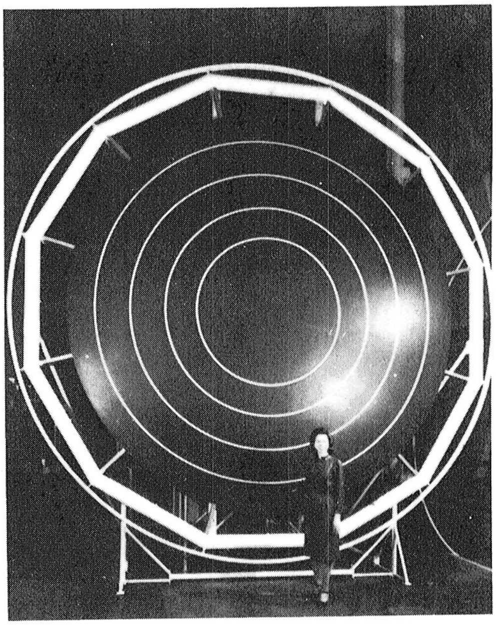
Effective surface control actuators for large systems will greatly improve the ability to compensate for alignment errors and operational deflections. Concepts for surface control of the wrap-rib and hoop/column antennas have been defined and are under evaluation. These systems may be required to compensate for environmentally induced deflections of the surface for very large systems.

Electrostatic shape control of a membrane is al~~so~~ under study. Objectives of this activity are to determine the feasibility of using electrostatic forces to control membrane surfaces, the selection of suitable materials, quantify the surface control capability of the technique, and to determine the effects of spacecraft charging. A 16-foot (5-m) model has been fabricated and surface-shaping tests initiated. Initial tests will be for the purpose of membrane material evaluation.

# SURFACE SENSING AND CONTROL

**SURFACE SENSING**





**ELECTROSTATIC SURFACE CONTROL**

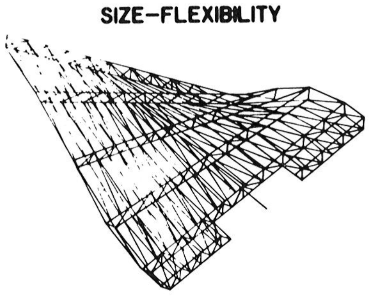
The unique structural characteristics of efficient space-configured spacecraft place a new requirement on control technology. Future large flexible antennas and space platforms will require precise attitude and shape control to satisfy mission requirements. New capabilities, such as active figure control, may be required to provide accurate surface contours and vibration suppression to ensure long-term structural integrity. Analyses have shown that these future structural systems will dynamically react with the control systems performance capability and potentially result in unstable control/structures interactions. Advanced control concepts tolerant of model errors with the capability to handle many interactive degrees of freedom must be developed to permit these large systems to satisfy performance requirements. The LSST Program supports a broad controls technology activity to address these needs.

Potential control problems associated with large space structures result from model inadequancies, including parameter uncertainty and variability, unmodeled nonlinearities, unmodeled disturbances, model truncation, and from interactions between the structure and the control systems. The LSST Program is sponsoring tasks at the Jet Propulsion Laboratory (JPL) which address these questions.

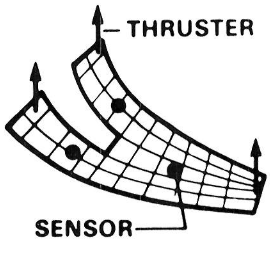
JPL and Purdue University are investigating the reduction of model order to minimize on-board computations and implementation complexity. To date, the investigators have defined the stability, controllability, and observability of dynamical systems established a finite element model of a generic configuration, and performed a modal analysis. The tasks are expected to provide model-order reduction methods for reduced-order controller design.

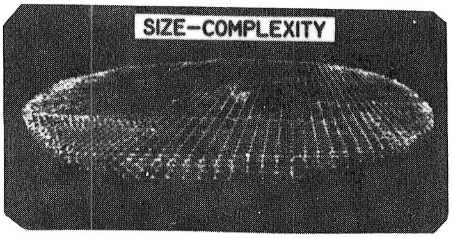
JPL is also attempting to design estimators capable of on-board detection of deficiencies in large structural dynamical models. This work is an extension of experience gained in state estimation and control of planetary spacecraft with flexible appendages. Finally, work is continuing to develop distributed control concepts. At JPL, a local distributed control system has been designed for beam-like structures. This technique is simpler to implement because of reduced dimensionality. Methods for static-shape estimation and sensor and actuator placement have also been studied. These studies are of fundamental importance and have wide potential application.

## CONTROL AND STABILIZATION



- DISTRIBUTED CONTROL
- MODEL ORDER REDUCTION
- MODEL ERROR ESTIMATION





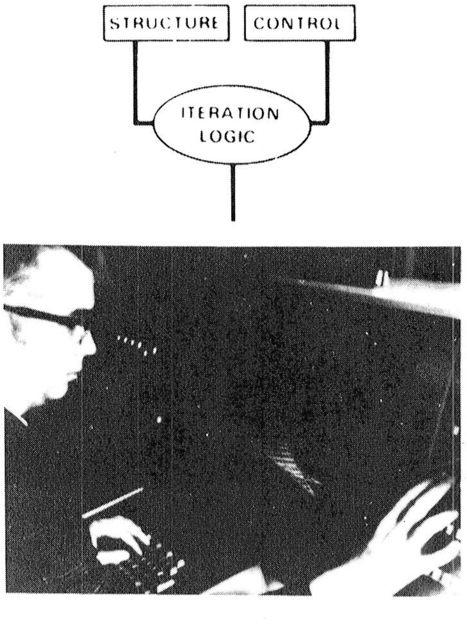
The capability to accurately perform the structural, thermal, and control analysis of a spacecraft in an efficient manner is important to spacecraft designers. Problems of interpretation and inefficiency frequently result from an absence of interaction between the various disciplines. These problems become more acute as the structural size and flexibility increases.

The LSST Program is sponsoring the development of an interactive analysis program at the Goddard Space Flight Center. The computer program will couple the thermal, structures, and control analysis. Early emphasis will be on the practical condensation of transient thermal analysis models and on improved technique for analyzing sampled data control systems. The end product of these tasks is expected to be an operational integrated analysis computer program suitable for preliminary design.

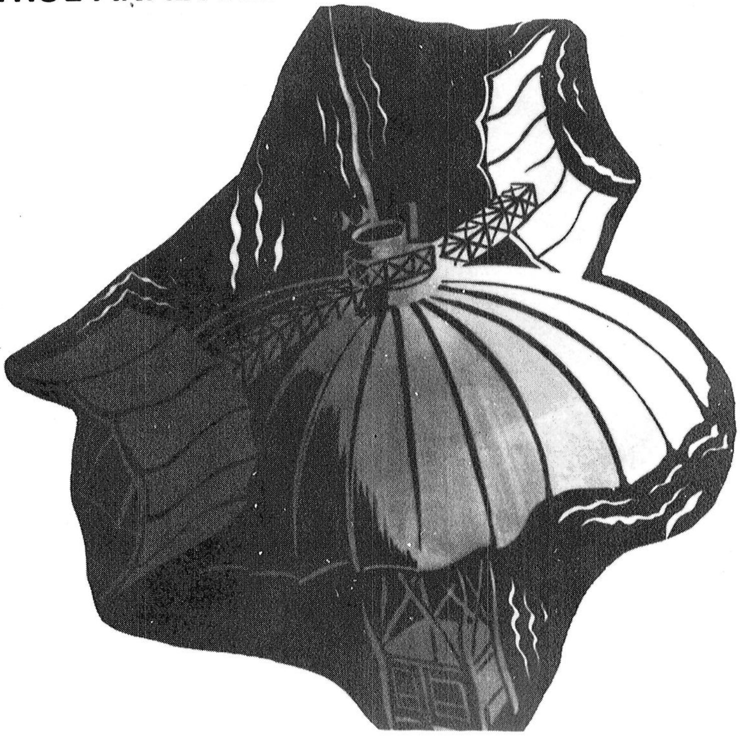
## INTEGRATED ANALYSIS AND DESIGN

### OBJECTIVE

- PROVIDE EFFICIENT CAPABILITY TO COUPLE STRUCTURAL, THERMAL, AND CONTROL ANALYSES



PRELIMINARY DESIGN



# CONCLUDING REMARKS

- LARGE SIZE WILL MAKE SIGNIFICANT CONTRIBUTIONS TO THE PERFORMANCE AND UTILITY OF SPACE SYSTEMS
- SHUTTLE CAPABILITIES WILL ENABLE THESE SYSTEMS
- TECHNOLOGY ADVANCEMENTS ARE NEEDED TO REDUCE THE COST AND RISK
- THE LSST PROGRAM IS PROVIDING TECHNOLOGY WHICH WILL ACCELERATE THE TECHNICAL AND ECONOMIC FEASIBILITY