

WRAP--RIB ANTENNA TECHNOLOGY DEVELOPMENT

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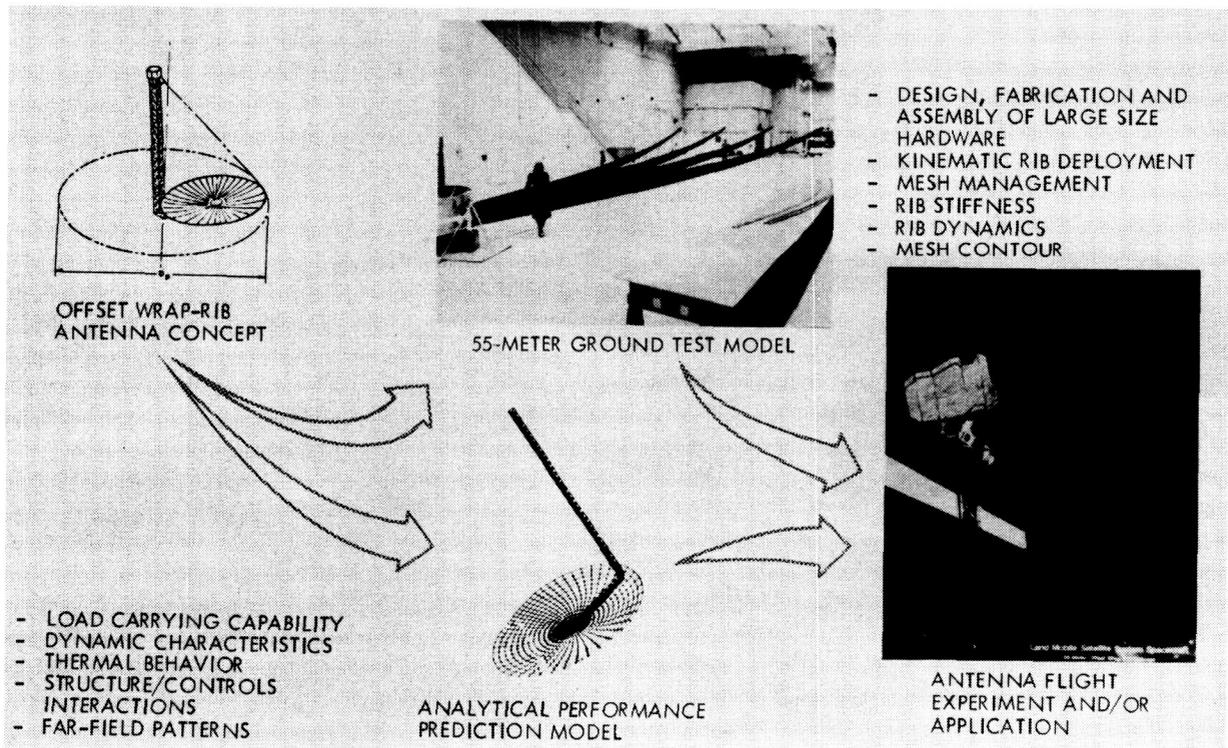
## LARGE DEPLOYABLE ANTENNA TECHNOLOGY DEVELOPMENT

The wrap-rib deployable antenna concept development is based on a combination of hardware development and testing along with extensive supporting analysis.

The proof-of-concept hardware models are large in size so they will address the same basic problems associated with the design fabrication, assembly and test as the full-scale systems which were selected to be 100 meters at the beginning of the program.

The hardware evaluation program consists of functional performance tests, design verification tests and analytical model verification tests. Functional testing consists of kinematic deployment, mesh management and verification of mechanical packaging efficiencies. Design verification consists of rib contour precision measurement, rib cross-section variation evaluation, rib materials characterizations and manufacturing imperfections assessment. Analytical model verification and refinement include mesh stiffness measurement, rib static and dynamic testing, mass measurement, and rib cross-section characterization.

This concept has been considered for a number of potential applications that include mobile communications, VLBI, and aircraft surveillance. In fact, baseline system configurations were developed by JPL, using the appropriate wrap-rib antenna, for all three classes of applications.

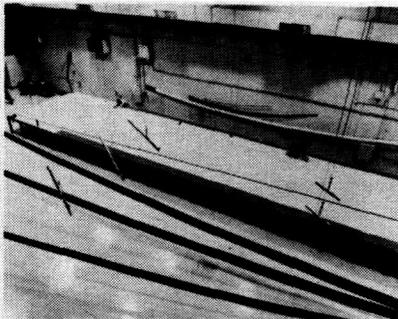


## PROOF-OF-CONCEPT WRAP-RIB ANTENNA MODELS

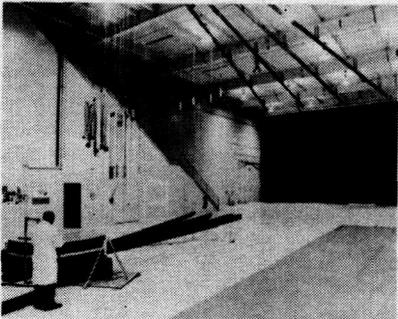
The proof-of-concept hardware model for the offset wrap-rib reflector is a sector of a 55-meter diameter structure. It consists of four graphite/epoxy lenticular ribs and three gold molybdenum wire mesh gore panels. The spacing of the ribs and density of the wire in the mesh are commensurate with surface accuracies accommodating 3 GHz RF operation.

Deployment of single ribs, four ribs, and the partial reflector is accommodated by a 0-G suspension system. This system is composed of a number of cables that utilize counter balances to vary the magnitude of support provided at five points along each rib. These cables are attached to bearings that ride along ceiling-mounted rails that follow the exact path of the ribs as they deploy from the hub structure. The cables are attached to the ribs at a distance of 5 meters from the hub and do not interfere with the mesh as it deploys from its stowed position between the ribs.

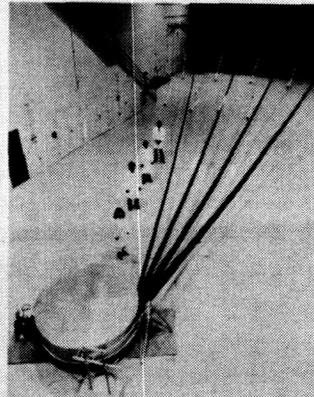
The mesh panels are laid out on bulk material that is loaded around its perimeter by a series of strings that go over pulleys for attachment to weights. The panels are then cut to the geometry required by the deployed ribs while maintaining the correct tension field.



MESH GORE PANEL FABRICATION



RIB DEPLOYMENT USING 0-G  
SUSPENSION SYSTEM



DEPLOYED SECTOR OF 55-METER  
REFLECTOR

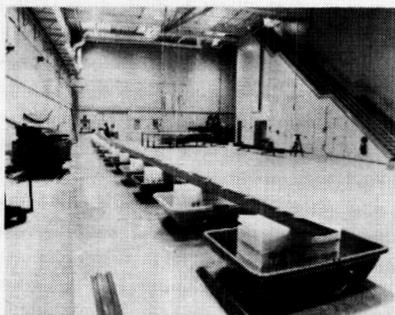
## WRAP-RIB ANTENNA TEST PROGRAM

The precision of curvature of the ribs was determined by establishing the geometry of a number of points along the unloaded structure with a theodolite. The rib structure was supported during the test by a number of soft foam blocks that were floating in individual tanks that were interconnected to maintain a common fluid level.

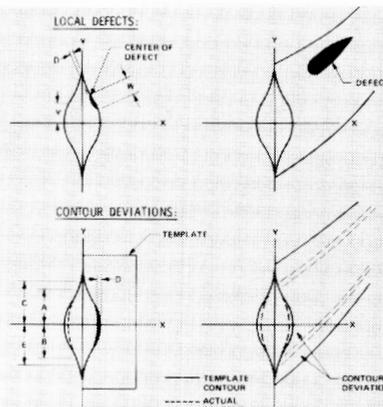
The measurement of the rib cross section was made by comparing the actual rib section with a number of templates that represent the desired lenticular shape as it varies along the rib. The rib deviations from the templates represent manufacturing error.

Static and dynamic characteristics of the ribs were determined by a series of simple static deflection and modal vibration tests. Each of the four ribs was tested for several deployed lengths for two different root boundary conditions. One rib root boundary was provided by the baseline deployment mechanism, the other by a rib root restraint.

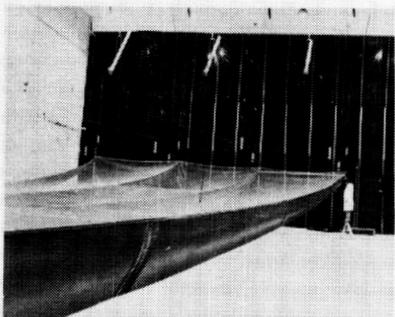
Mesh management was evaluated by repeated deployments of several schemes for stowing the mesh panels. These included folding the mesh on top of the ribs, partially between the ribs and entirely between the ribs. The most successful approach turned out to be folding the mesh between the ribs.



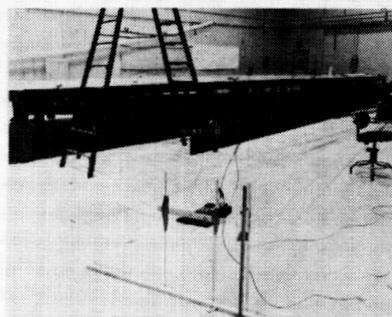
RIB CONTOUR MEASUREMENT



RIB CROSS SECTION



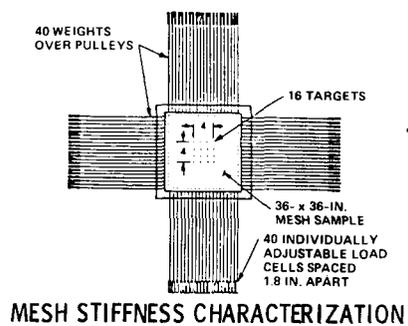
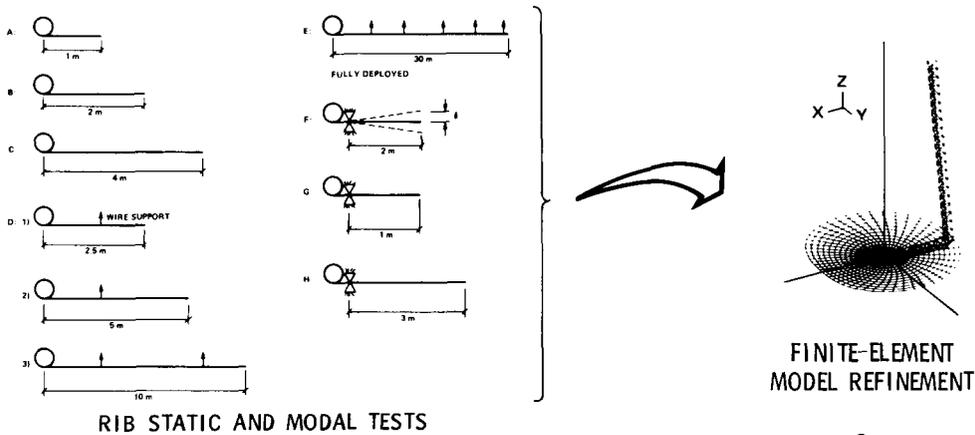
MESH MANAGEMENT



RIB STATIC AND MODAL TEST

## GROUND-BASED STRUCTURAL TEST TECHNIQUES

Ground-based test limitations of large, very flexible space structures preclude the meaningful preflight verification and demonstration of predicted space performance. The experimental determination of the practical limits of ground-based testing and the effects of manufacturing variations on structural performance can best be established by evaluation of full-size flight-type hardware. The 55-meter diameter hardware model has all the characteristics of large space structures, i.e., low frequency, high modal density, and nonlinear stiffness. The existing data base for this full-size hardware accounts for the design, fabrication, assembly, and testing of a number of different rib structures and rib structures attached to nonlinear mesh. The results of current and planned static and dynamic testing for a number of different boundary conditions for the same basic structure will be correlated with analytical predictions to determine the extent of testing required to adequately characterize this class of large space structures. Additionally, the manufacturing variations on full-sized, lightweight space hardware which have been experimentally determined will be used analytically to establish their sensitivity on structural system performance.

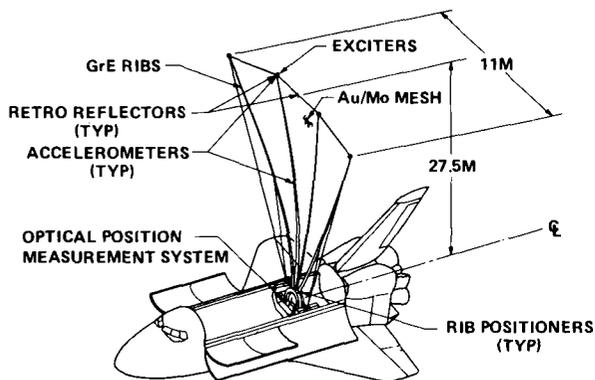


## WRAP-RIB ANTENNA FLIGHT EXPERIMENTS

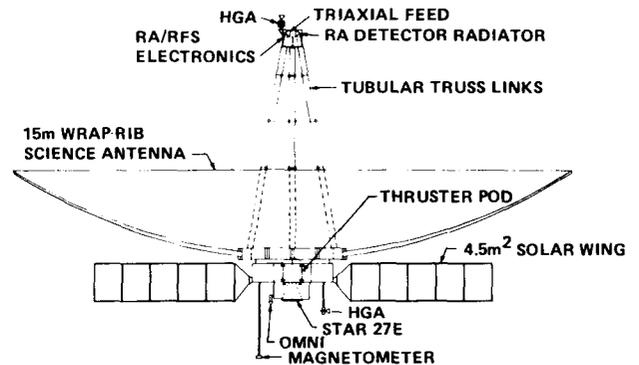
A number of flight experiments focused on extending and verifying technology for large deployable antenna systems have been defined over the past 12 or so years. The cost for either Shuttle-based or free-flying antenna experiments in the 30- to 50-meter size range has been prohibitive regardless of the potential technical value. This suggests the need for lower cost and less ambitious flight experiments. Such experiments might be based on using upgraded existing development hardware or by combining a basic science mission with a low-risk antenna technology experiment.

A Shuttle-based experiment using an upgraded version of the wrap-rib proof-of-concept model, which is a sector of a 55-meter diameter offset reflector, and the STEP has the benefits of using a generic large space structure. Namely, it has the structural characteristics of low frequencies, high modal density and coupling and nonlinear dynamic response. Such an experiment would address initial position variations, mesh management, surface precision and structural and thermal characteristics.

The QUASAT baseline science mission uses a 15-meter deployable K-band antenna for VLBI. This science antenna could be upgraded by adding the capability for surface measurement, surface adjustment and dynamic control. This would accommodate an experiment addressing initial position, surface precision, feed structure alignment and adjustment, thermal distortion and active surface control at a small fraction of the total mission cost.



STS ATTACHED EXPERIMENT WITH  
PROOF-OF-CONCEPT 55-METER MODEL  
USING STEP

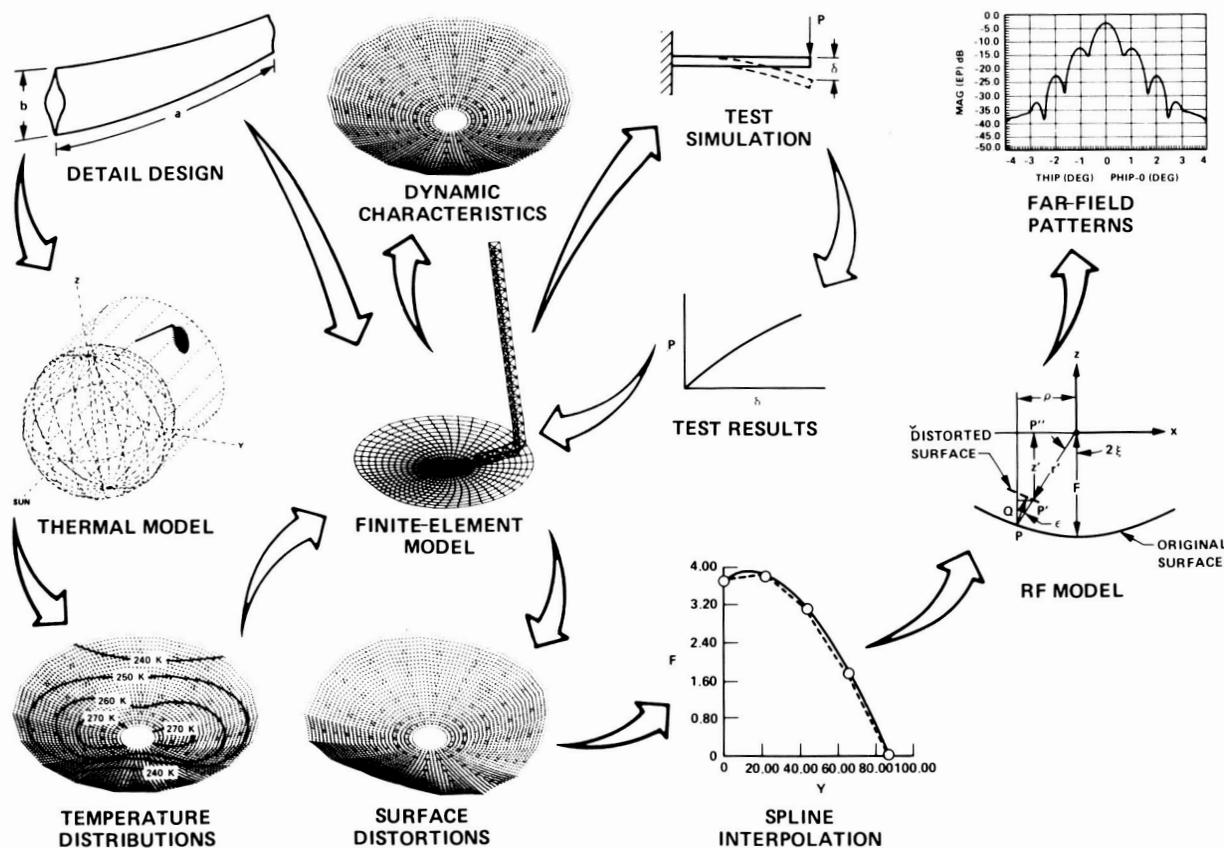


QUASAT FREE FLYER SCIENCE  
AND TECHNOLOGY MISSION

## ANTENNA SYSTEM INTEGRATED ANALYSIS

The deployable antenna system integrated analysis capability was developed to evaluate the potential value of antennas for classes of applications, to optimize specific structures for specific applications and to predict on-orbit system performance.

The finite-element model and thermal model were initially developed with results of the structural preliminary design. Results of component and assembly structural tests were used to refine the antenna system finite-element model. The thermal model was used to determine the antenna system temperature distributions for different Sun angles and orbital points. These temperature distributions are used with the finite-element model, which accounts for the concept surface approximation error to determine the overall aperture distortion. Additionally, this model generates the system dynamic characteristics which are needed for structural and control system evaluation and development. The surface errors, which are defined in terms of the coordinates and displacements of the grid points, are transformed into continuous functions by means of a spline interpolation routine. This result is the input to the RF analysis which utilizes a ray-tracing technique to generate the antenna for field patterns.

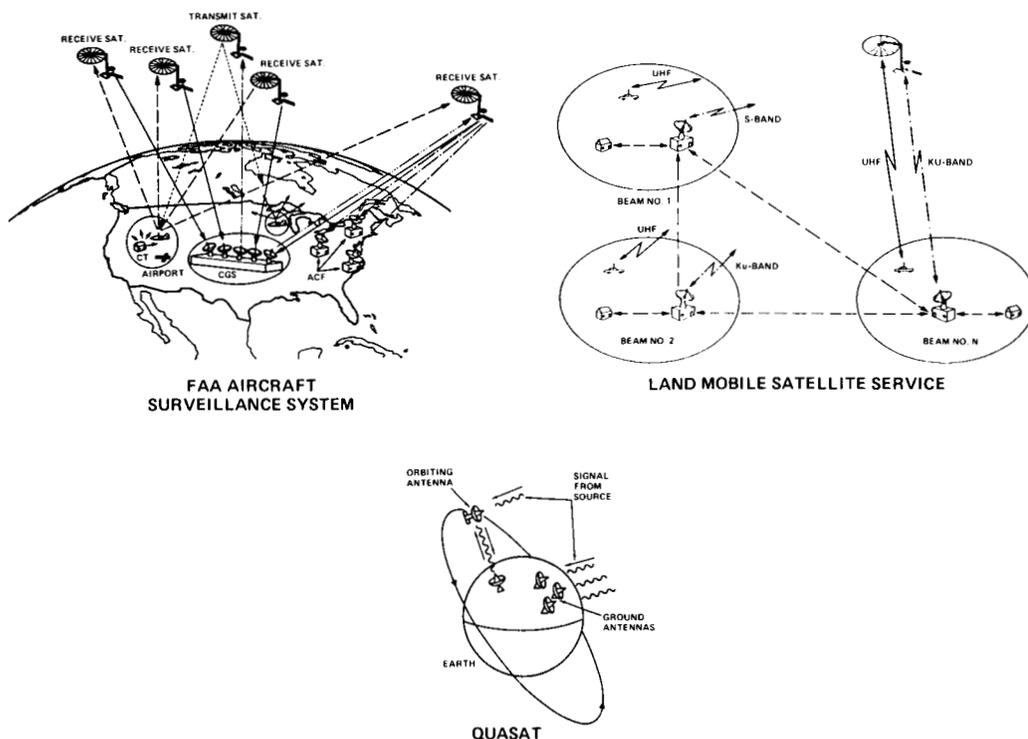


## POTENTIAL ANTENNA APPLICATIONS

Air Traffic Control (ATC) is currently accomplished by means of a network of terrestrial surveillance radars, airborne transponders, and an extensive communications network. The FAA is investigating the applicability of satellites to various aspects of ATC. A current air traffic surveillance study has shown the feasibility of using 5-8 geosynchronous satellite networks for supplementing the terrestrial system and increasing coverage. The satellites utilize an unblocked aperture antenna from 15 to 150 beams at L-band.

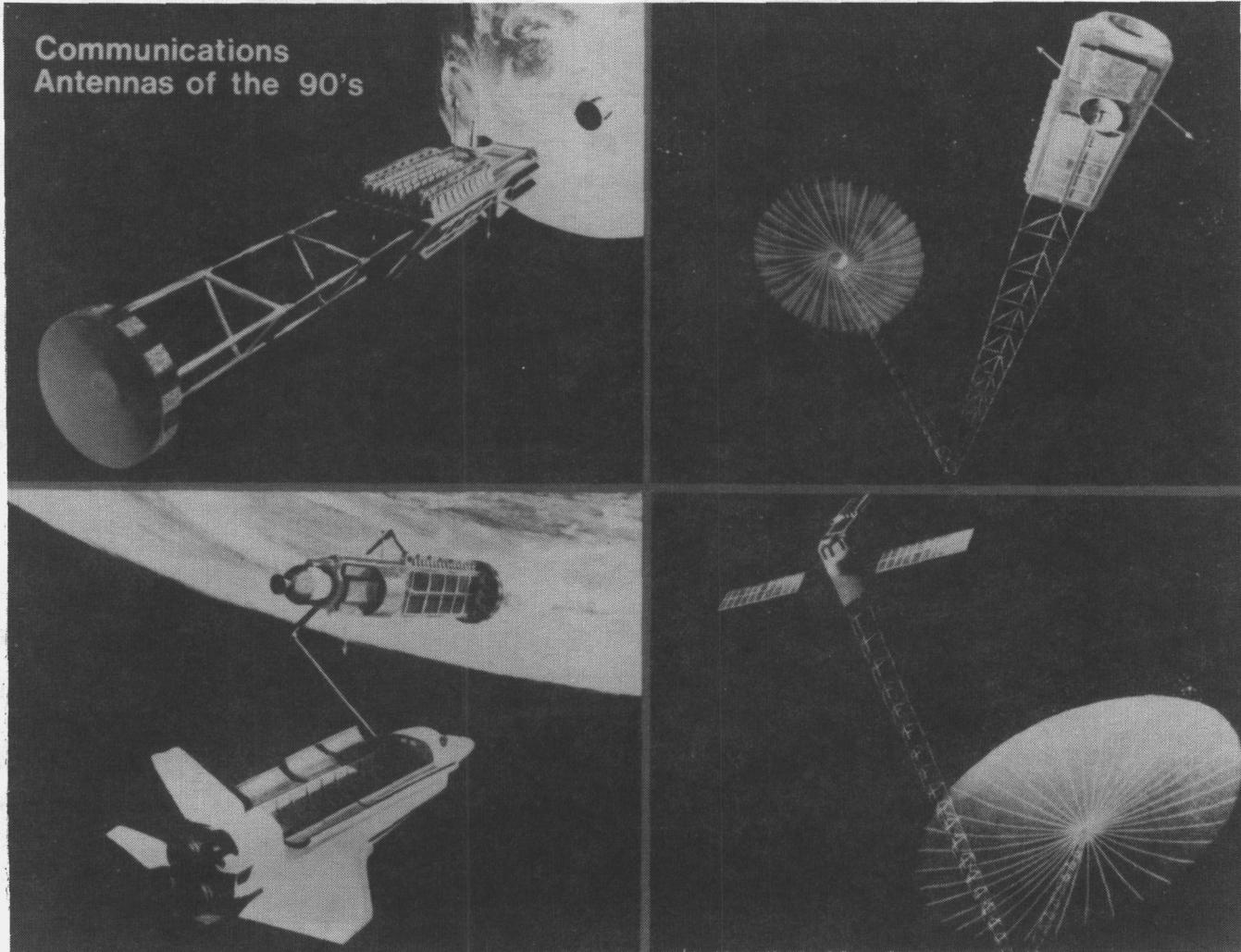
The QUASAT mission concept involves a free-flying, Earth orbital, large radio telescope, designed to observe astronomical radio sources simultaneously with ground telescopes. By using VLBI (Very Long Baseline Interferometry) data processing, a synthesized aperture larger than the diameter of the Earth can be achieved by the concept. This mission is based on a large deployable antenna, 15-20 meters in diameter, for operation at L-band, C-band, and K-band, the latter being of primary interest.

A mobile satellite system is a satellite-based communications network that provides voice and data communications to mobile users throughout a vast geographical area. Such a system is composed of a large number of users with small-size, low-gain UHF transmitters and a few large aperture, high-gain, multiple-beam antenna systems in parking orbit. The space antenna size is a function of the service desired and could range from 10 to 50 meters in diameter.



## OFFSET WRAP-RIB ANTENNA DEVELOPMENT PROGRAM

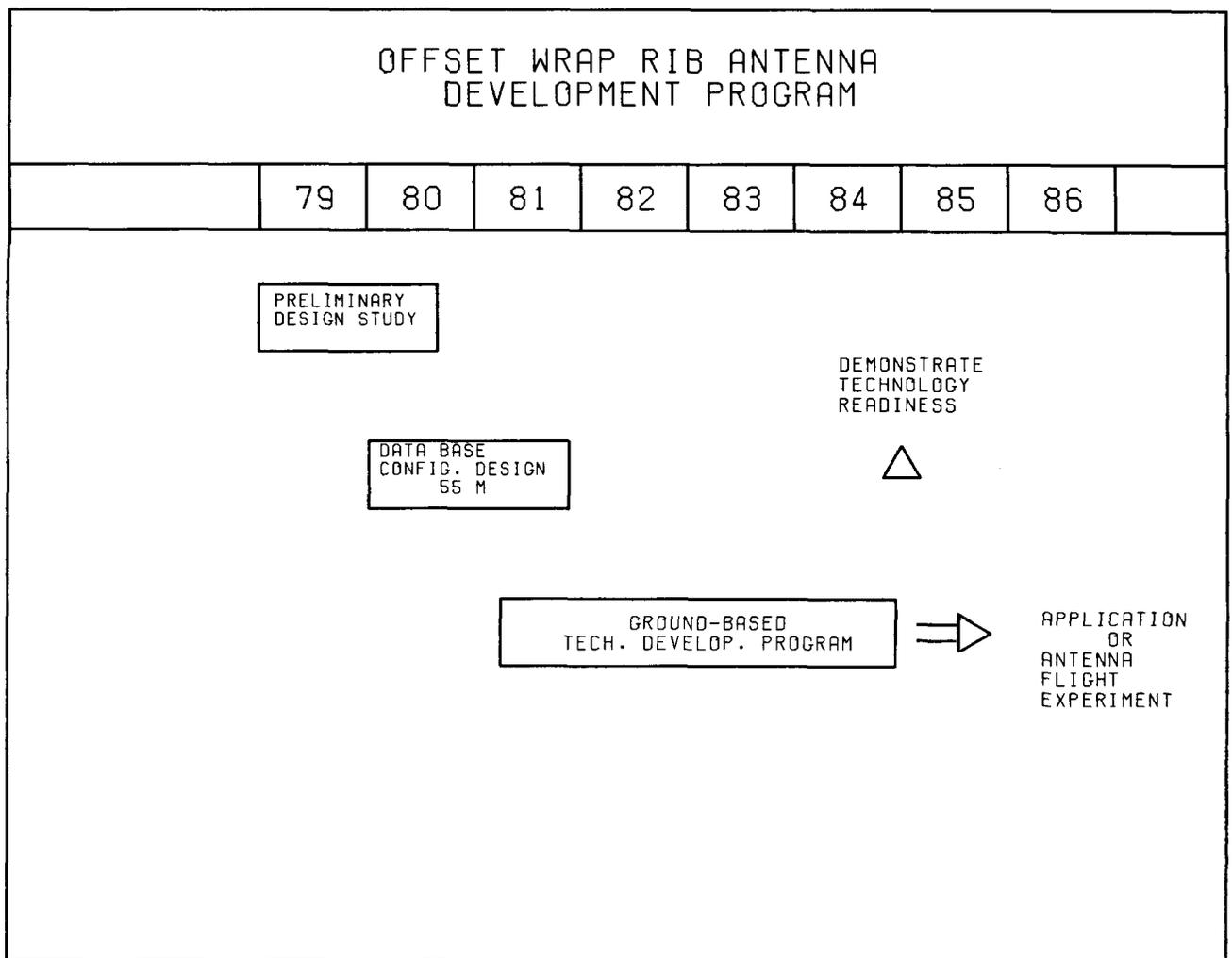
The antenna development program of the offset wrap-rib antenna concept, developed by Lockheed Missiles and Space Company and sponsored by NASA, is based on a ground test program of "proof-of-concept" hardware with analytical estimates of potential on-orbit performance conducted by Lockheed and Jet Propulsion Laboratories. The system concept is presented below and depicts a 100-m-diameter communications antenna.



## DEVELOPMENT PROGRAM

The elements of the development program (shown below) are the preliminary design study, data base configuration design, and ground-based technology development.

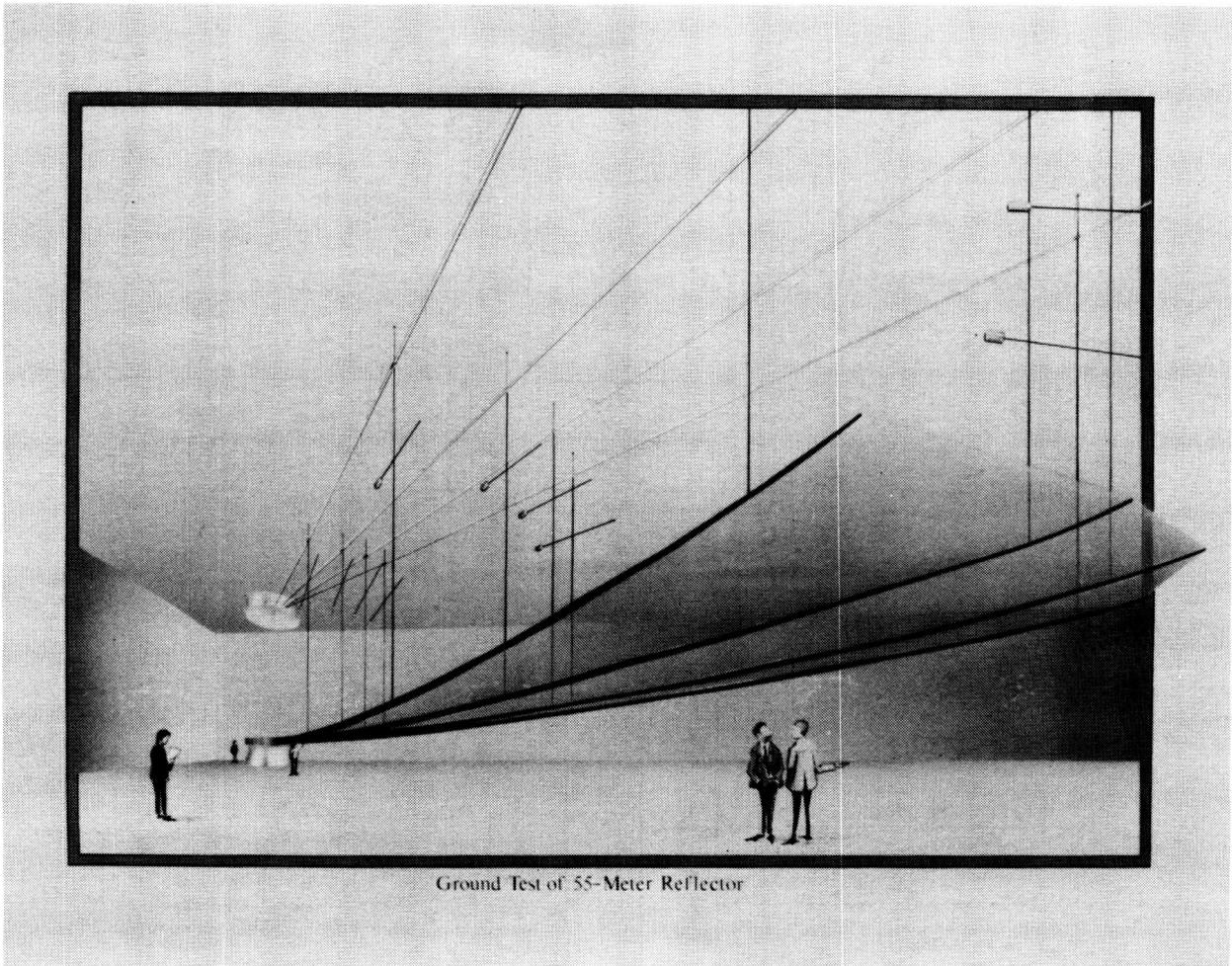
The preliminary design study characterized offset and symmetric reflectors for missions in the 100-m to 150-m-diameter range, identified critical technologies, ROM cost and schedules for development, and developed a technology plan for a low-cost, low-risk "proof-of-concept" demonstration.



## GROUND-BASED TEST PROGRAM

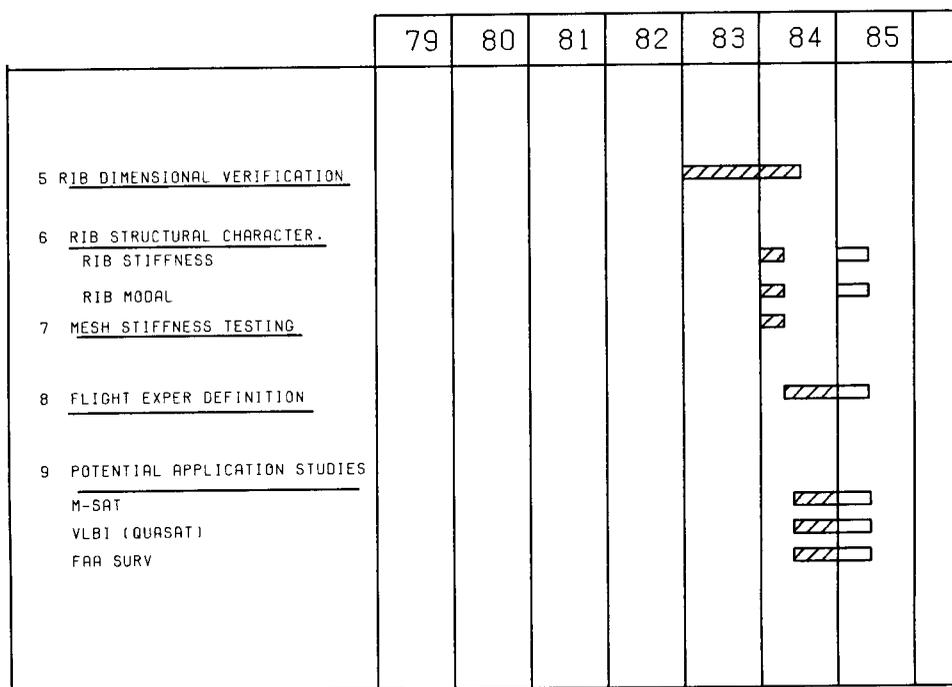
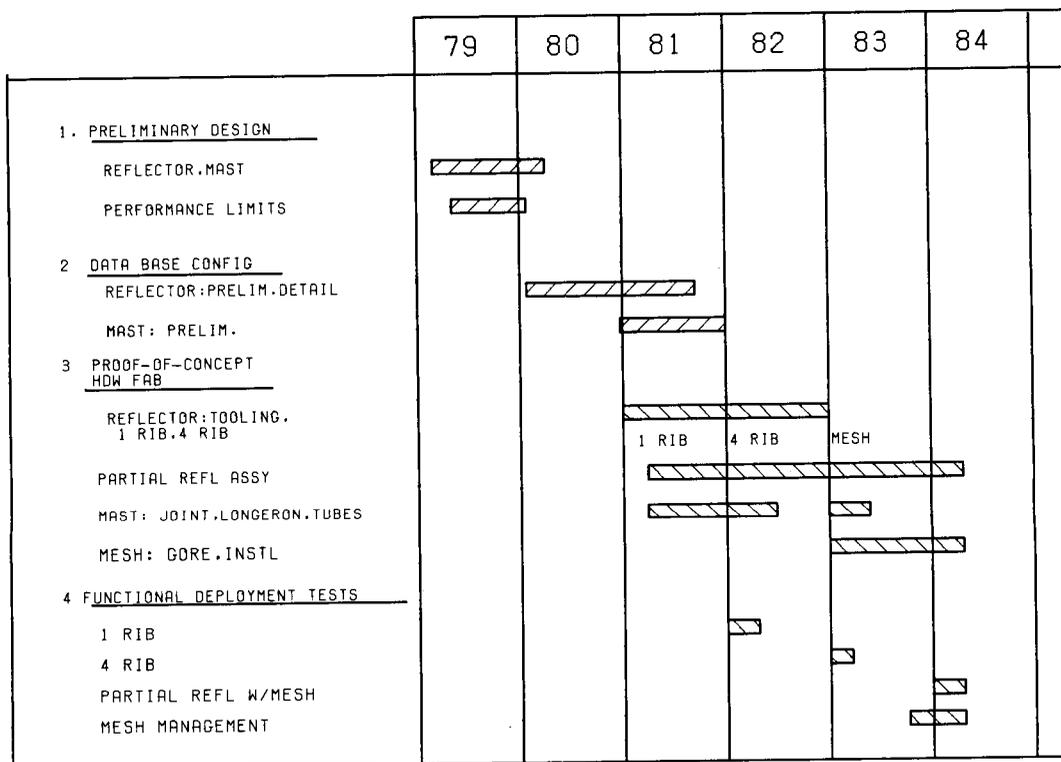
The data base configuration established a 55-m-diameter offset wrap-rib reflector design that could be used to design and demonstrate component manufacturing and assembly processes that are scalable to a 100-m to 150-m size and testable in a 1-G environment.

The ground-based technology program addressed the technology development required in design, manufacture, assembly and testing of the full-sized "proof-of-concept" hardware. Component ground testing provided design algorithm and analytical performance model updating. The partial reflector "proof-of-concept" hardware provided the test bed for 1-G deployment testing (shown below) and the final technology readiness demonstration for this concept.



### PROGRAM TASKS

The specific program tasks are described in these two figures and present the full program activity to date.



## PROGRESS AGAINST OBJECTIVES

Significant progress was made in 1983 and 1984 in the area of component ground testing for analytical model updating. Paramount was the completion and deployment testing of the 55-meter partial reflector "proof-of-concept" hardware to demonstrate technology readiness. This figure presents an overview of completed tasks.

### 1983 - 1984 PROGRESS

#### (TASKS COMPLETED)

- RIB DIMENSIONAL VERIFICATION
- RIB STRUCTURAL CHARACTERIZATION
- MESH STIFFNESS TESTING
- MESH GORE FABRICATION AND INSTALLATION
- MESH MANAGEMENT STUDIES
- PARTIAL REFLECTOR DEPLOYMENT TESTING
- FLIGHT EXPERIMENT DEFINITION STUDY
- POTENTIAL APPLICATION STUDIES

## RIB TOOLING

The engineering tool definition was accomplished using CADAM (Computer Graphics Augmented Design and Manufacturing System). The computer-generated numerical control tape drove the gerber flatbed plotter to scribe the flat pattern part for the tool contour templates to be used in bump forming and bump forming guidelines. The scribed Invar flat pattern sheets were bump formed in a hydraulic brake using steel dies against a hard rubber reactor. The three-dimensional variation of tool layup surface was maintained using the bump-forming guidelines for reflector curvature and the cross-sectional rib contour templates at intervals along the length of the tool. The finished formed Invar layup surface was placed in position over an Invar tool base and welded. To manufacture the rib segments, epoxy-impregnated graphite was placed on the layup tool in three layers (45/0/45). The completed graphite/epoxy layups were vacuum bagged and cured under temperature and pressured in an autoclave. The cured rib segments were in twenty-foot sections. The root end rib segment included a titanium rib hinge stiffener which was co-cured with the graphite/epoxy rib. The five rib segments were then placed end to end, aligned, marked, trimmed, butt jointed, spliced with strap and adhesive, vacuum bagged, and the adhesive allowed to cure. This completes a semi-lenticular rib half shown below.



## DEPLOYMENT MECHANISM AND RIB DEVELOPMENT

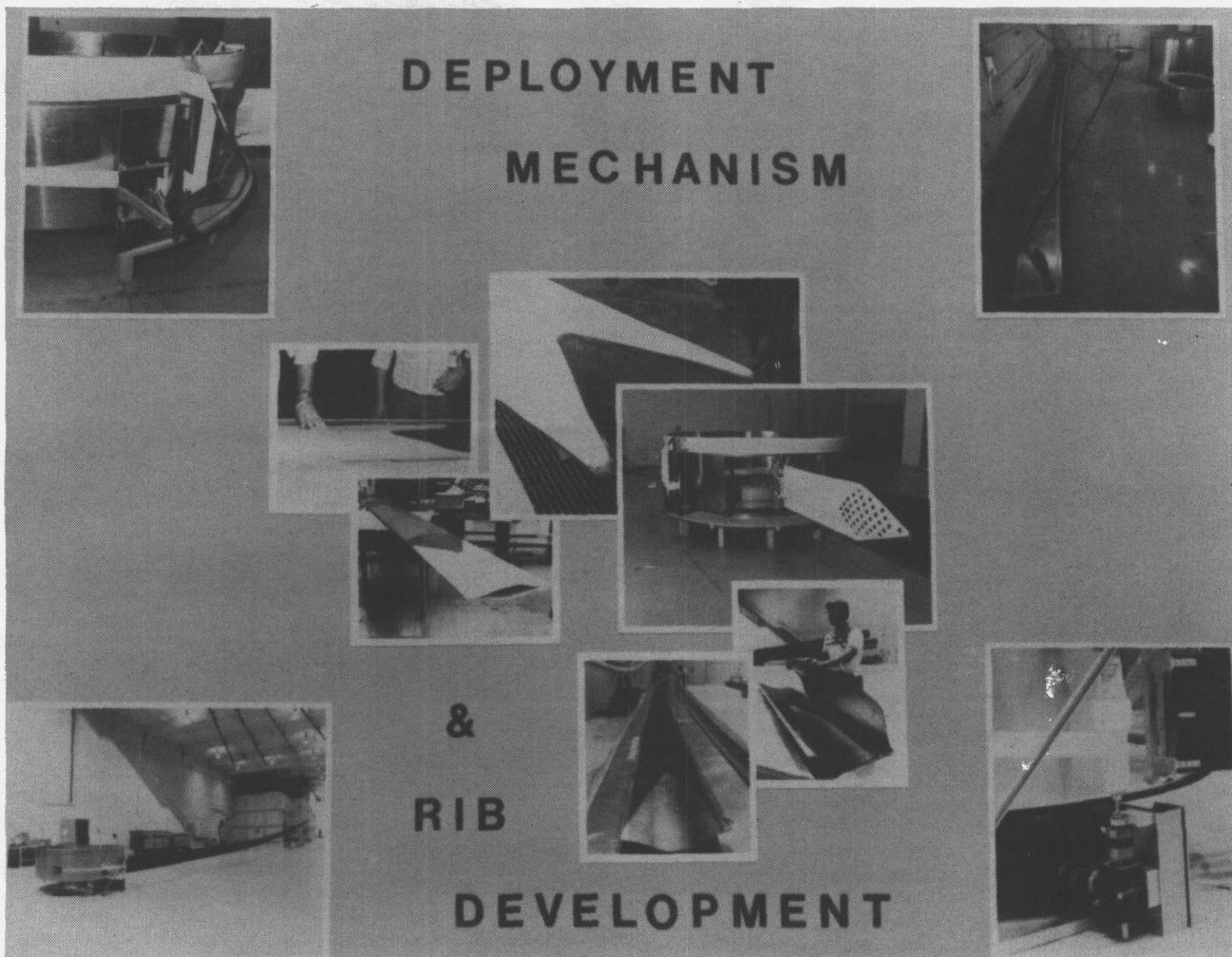
Several concepts for the rib root segment/hub interface were evaluated. The design requirements for the interface were to:

- Provide for flattening of rib for stowage
- Provide for 90° rotation of rib for stowage and deployment
- Provide for maximum deployed stiffness transfer from the rib to the hub

The design developed was a titanium root stiffener, co-cured with the graphite/epoxy rib and the rib hinge bonded and riveted to the stiffener.

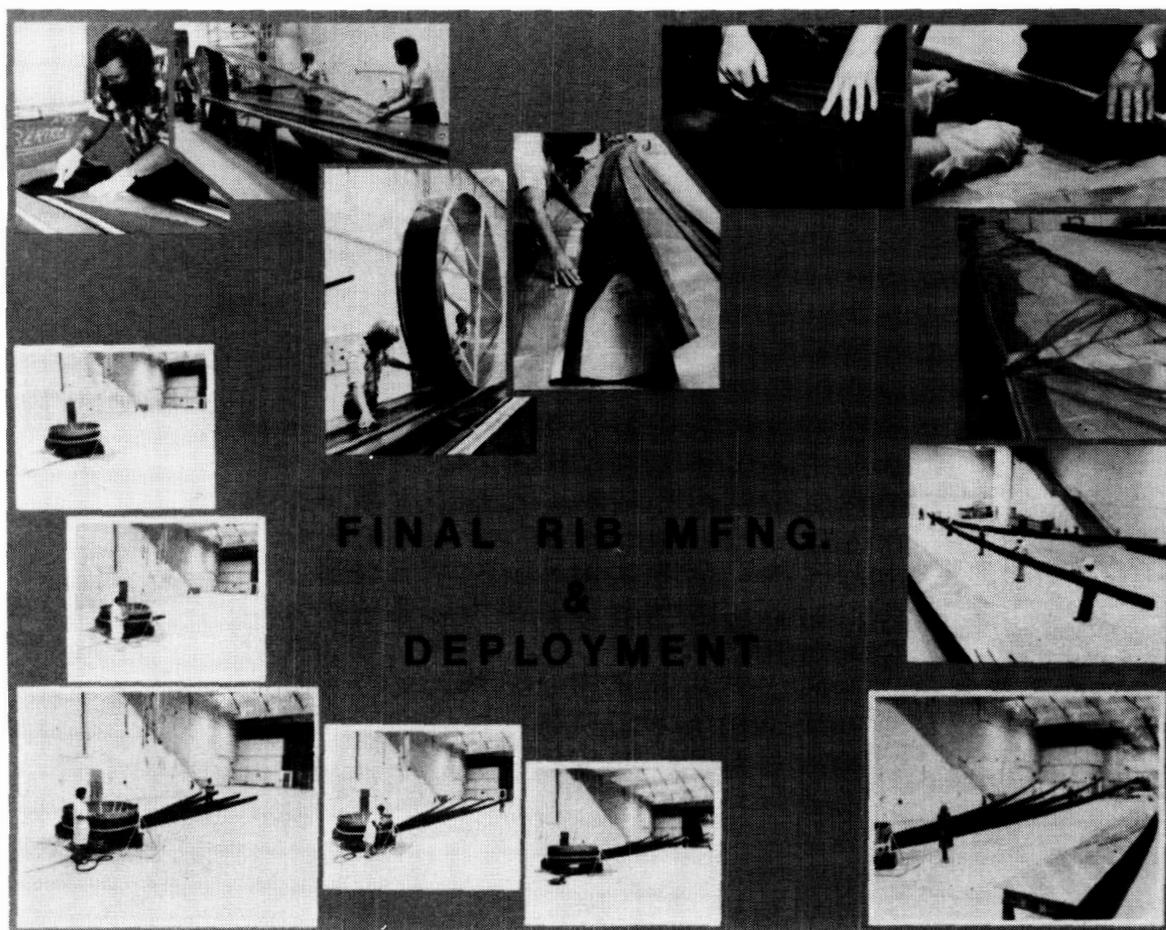
The initial deployment control mechanism was a tape "re-wrap" concept operated successfully except the tape tension could not be controlled adequately. The developed design concept employed a tape spool deployment mechanism utilizing an electromagnetic clutch/brake with a variable speed motor.

A single-rib system was then integrated with a simulated reflector hub and special test equipment (STE) and on November 6, 1981 the system was successfully cycled through the deployment and stowing operations shown below.



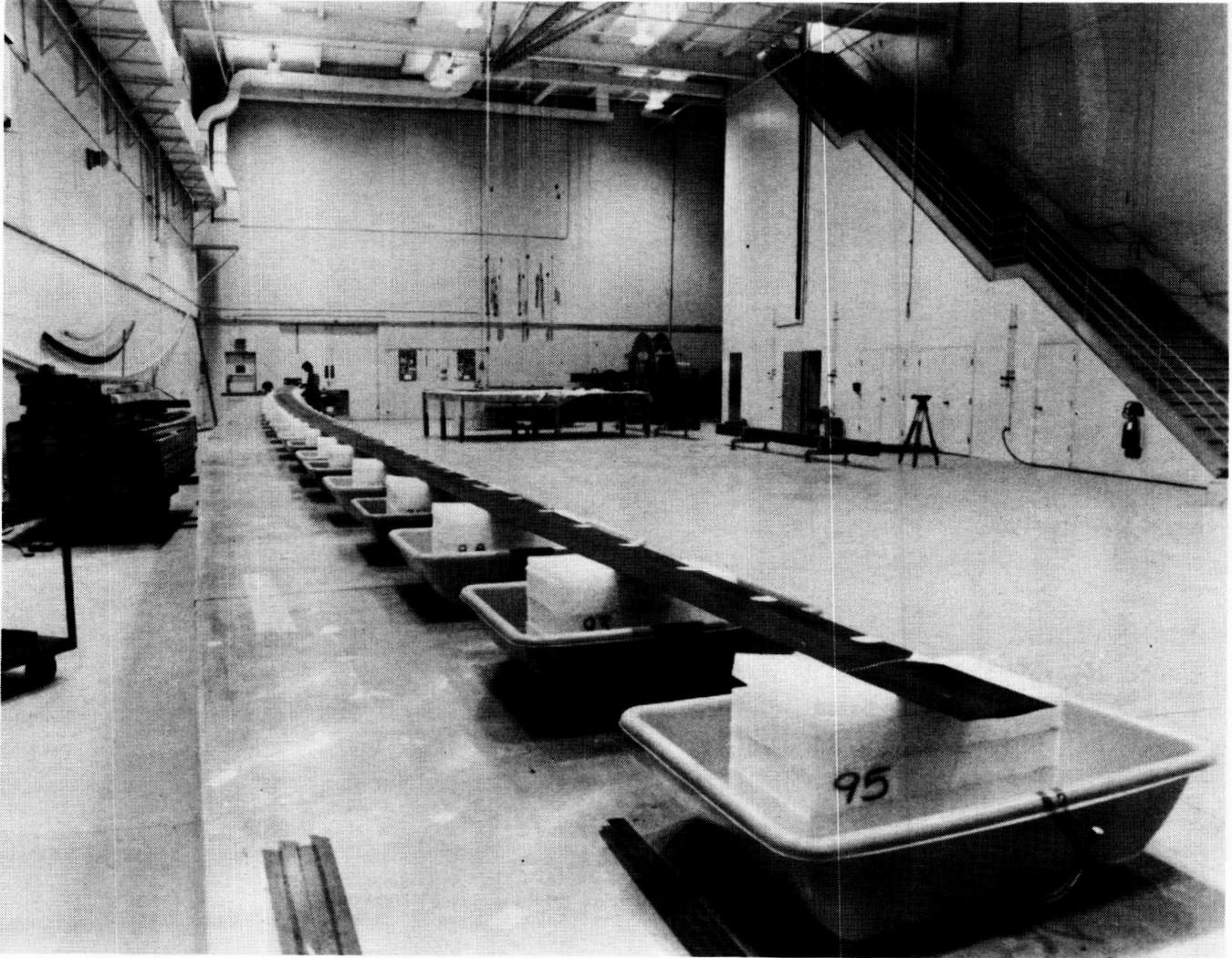
## FINAL RIB MANUFACTURING AND DEPLOYMENT

Semi-lenticular rib halves are bonded together along the upper and lower longitudinal edges to generate a full lenticular cross section. Since each rib half was spliced with the inside face down on the work table, one rib half was coiled onto a large diameter spool and unrolled in the required orientation adjacent to the other rib for lenticular bonding. The two rib half sections were aligned, bonded along the longitudinal edges, vacuum bagged and allowed to cure at room temperature. The rib was trimmed to the final configuration. On November 4, 1982, a four-rib partial reflector was successfully cycled through deployment and stowing cycles shown in this figure.



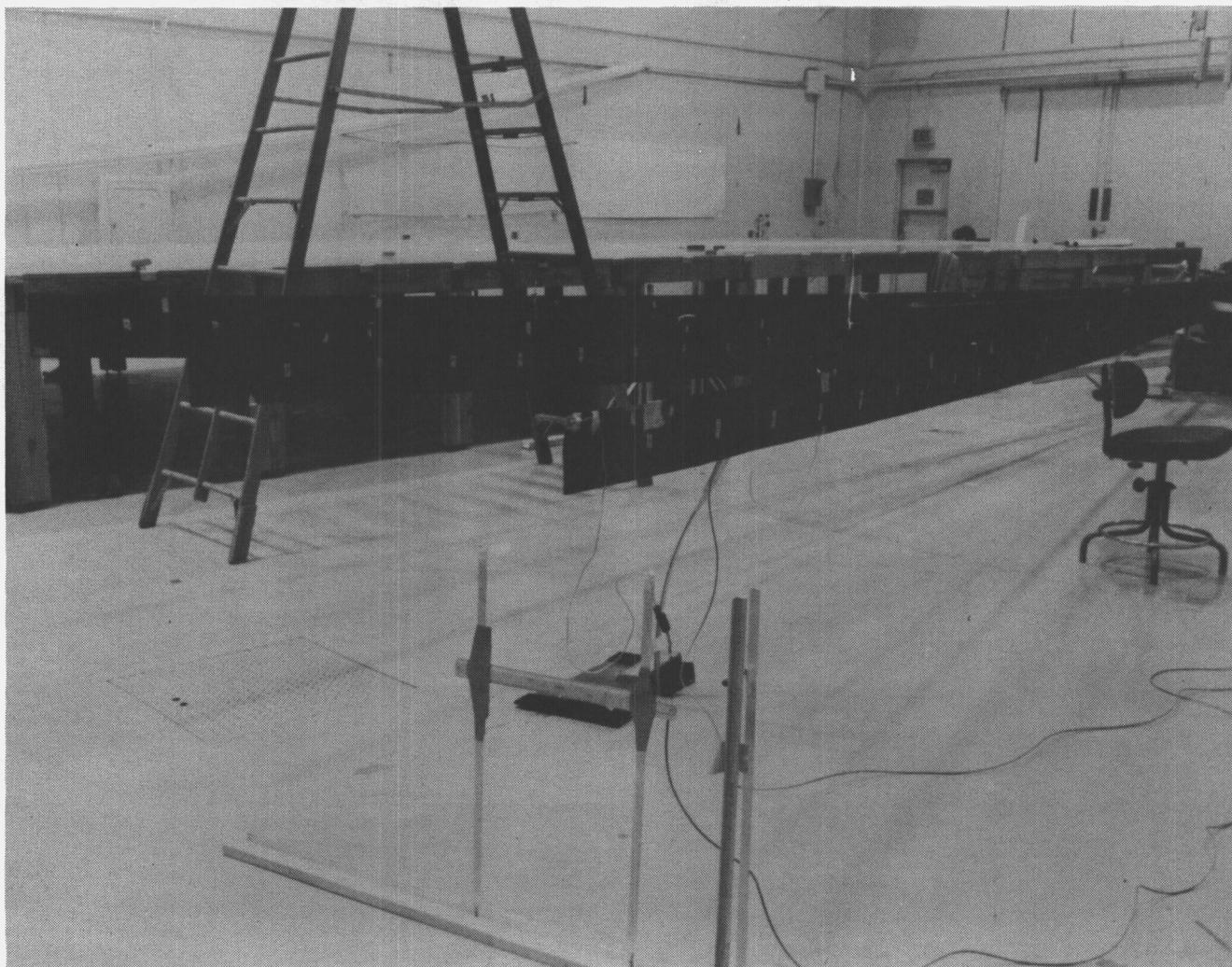
## RIB MEASUREMENT

The concave contour edge of the rib assembly was measured in a simulated free state by a flotation system to verify the rib contour manufacturing to design requirement tolerances. The contour was measured by a triangulation method using two theodolites and targeted on a series of hairline marks scribed on the concave rib edge, as shown below.



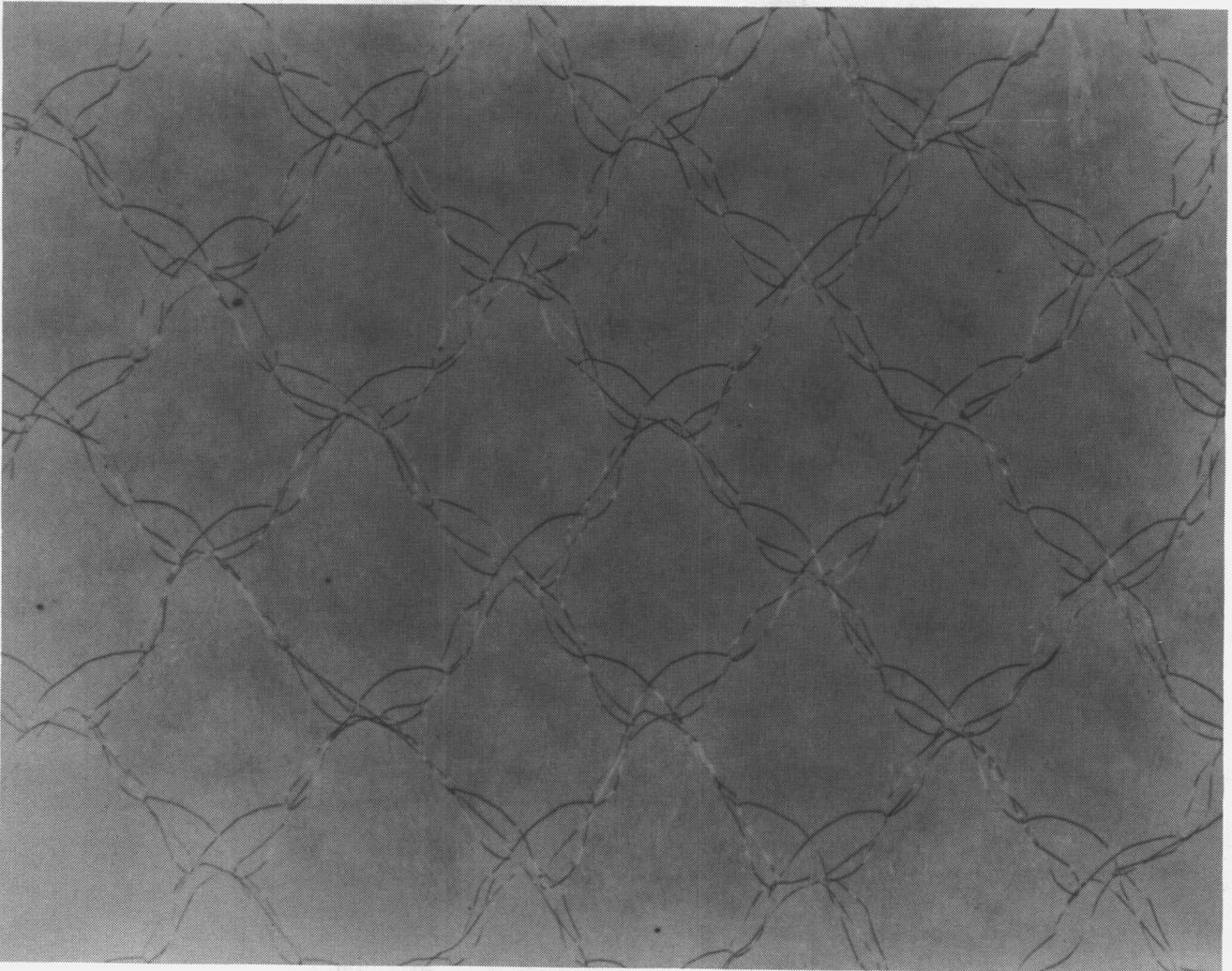
## RIB STRUCTURAL CHARACTERIZATION

Static deflection and modal tests were performed to obtain structural and dynamic data of the ribs at various stages of deployment. The test series was comprised of twelve test configurations, eight modal and four static deflection. The data will be used to upgrade structural analytical models for rib characterization (shown in this figure).



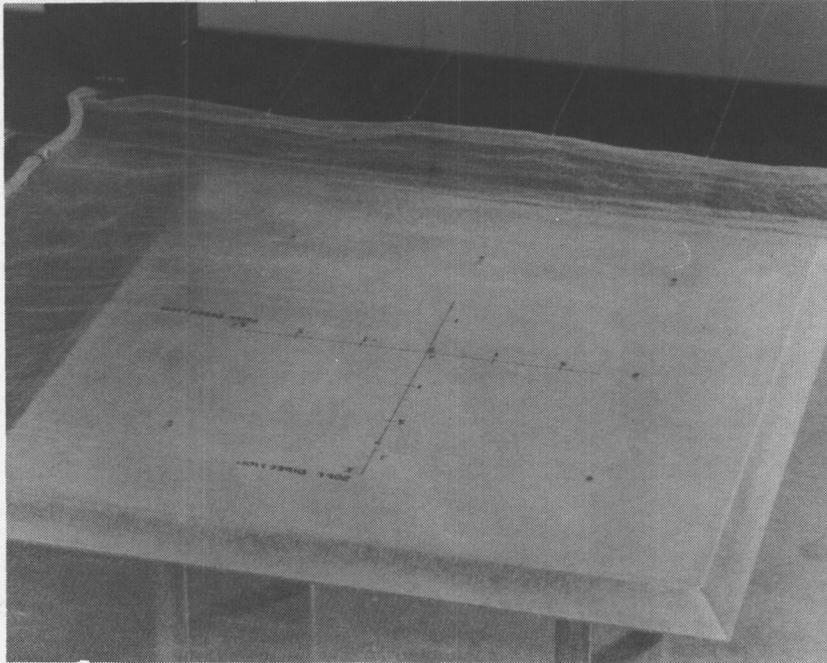
## MESH PANEL

The material, type, and cell size for the mesh panel are: (1) material: molybdenum wire (0.0012 dia), gold plated, (2) type: knit, diamond tricot, and (3) cell size: 4 cells/inch (3 GHz), see figure below.



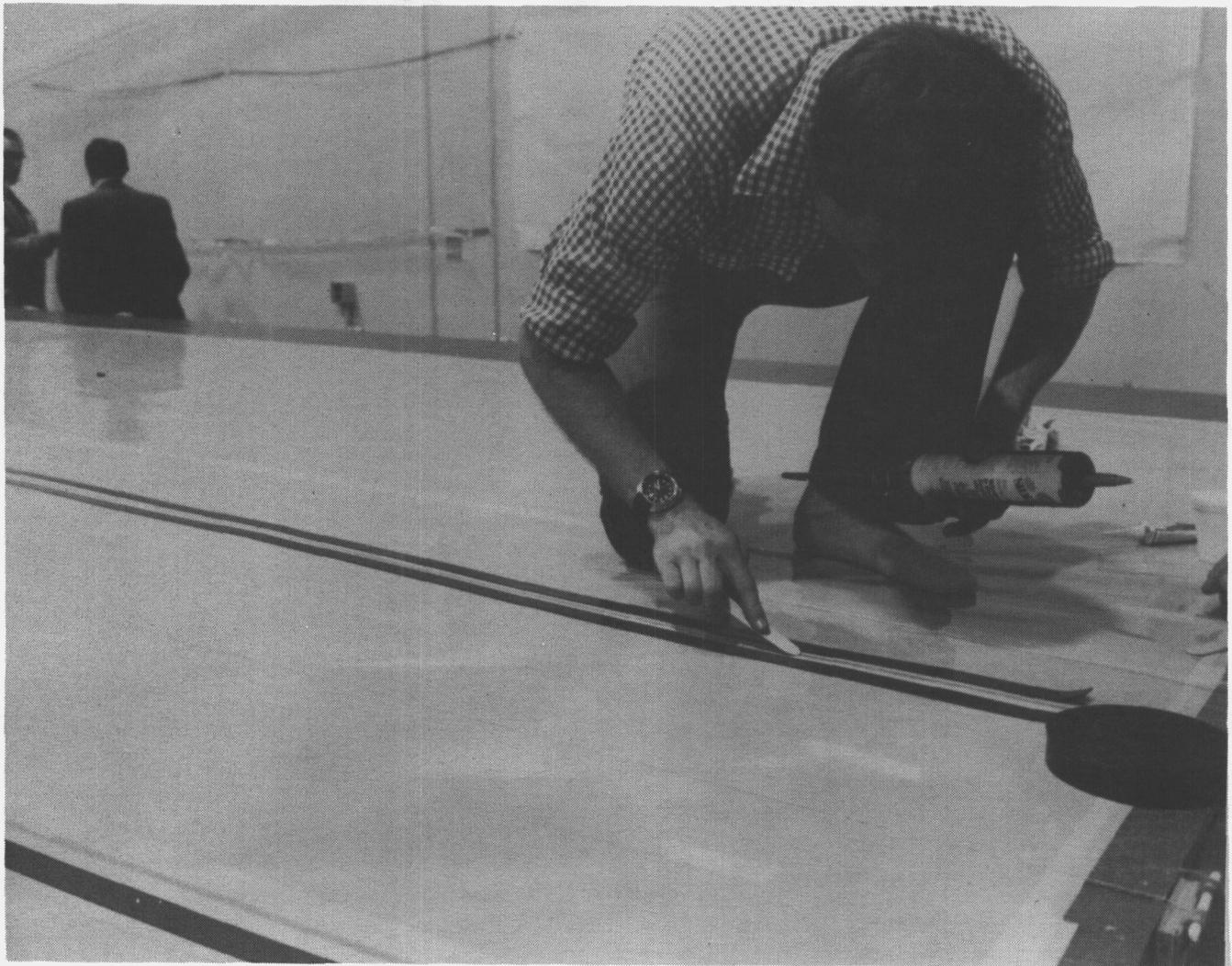
## MESH STRUCTURAL CHARACTERIZATION

The mesh is tested to determine structural characteristics and effects due to various preloads. The biaxial stiffness test is accomplished on a special test fixture. The preloads are applied to the mesh and the strain response is measured via a camera located directly above the mesh. Through an accurate digital encoder the results are entered via keyboard to a computer for processing and storage (as shown in these figures).

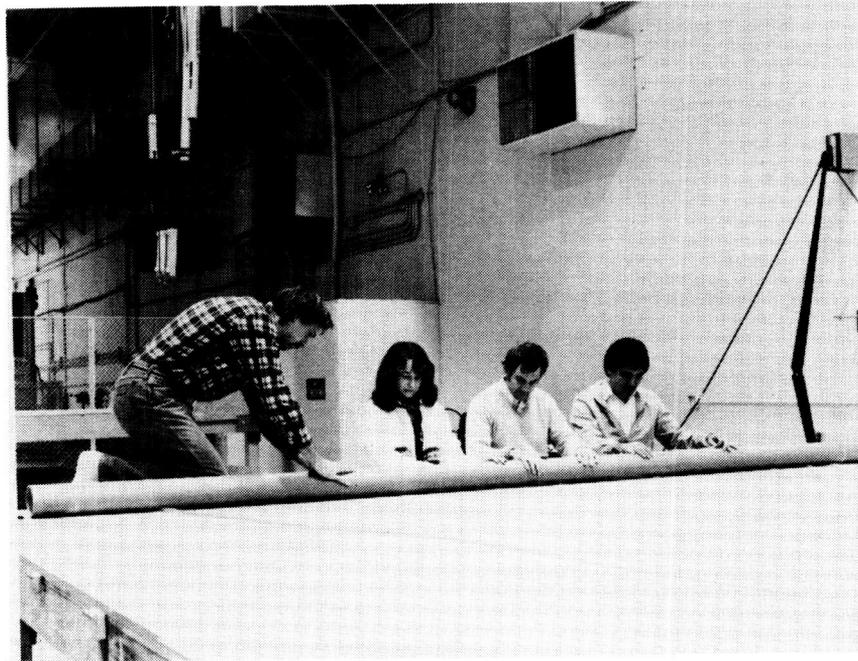
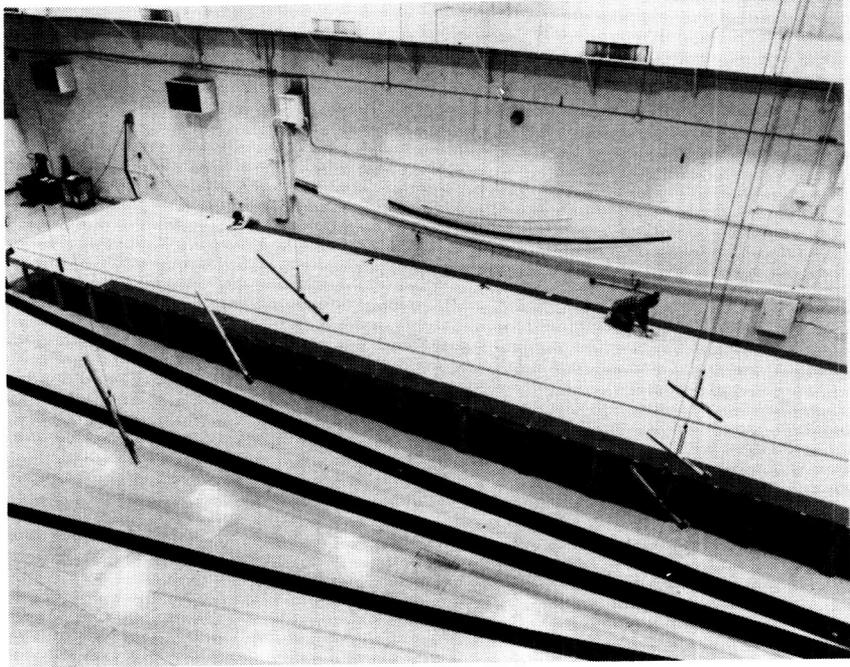


## MESH GORE FABRICATION

The mesh was unrolled onto a mylar flat pattern on a 16- x 92-ft table. The mesh was preloaded at the ends with weights and secured with magnetic tape. The Kevlar end condition was attached to the mesh with adhesive and cured at room temperature. The mesh gore was trimmed to the final size and rolled onto a tube ready for final installation (see the figure below and the next two figures).

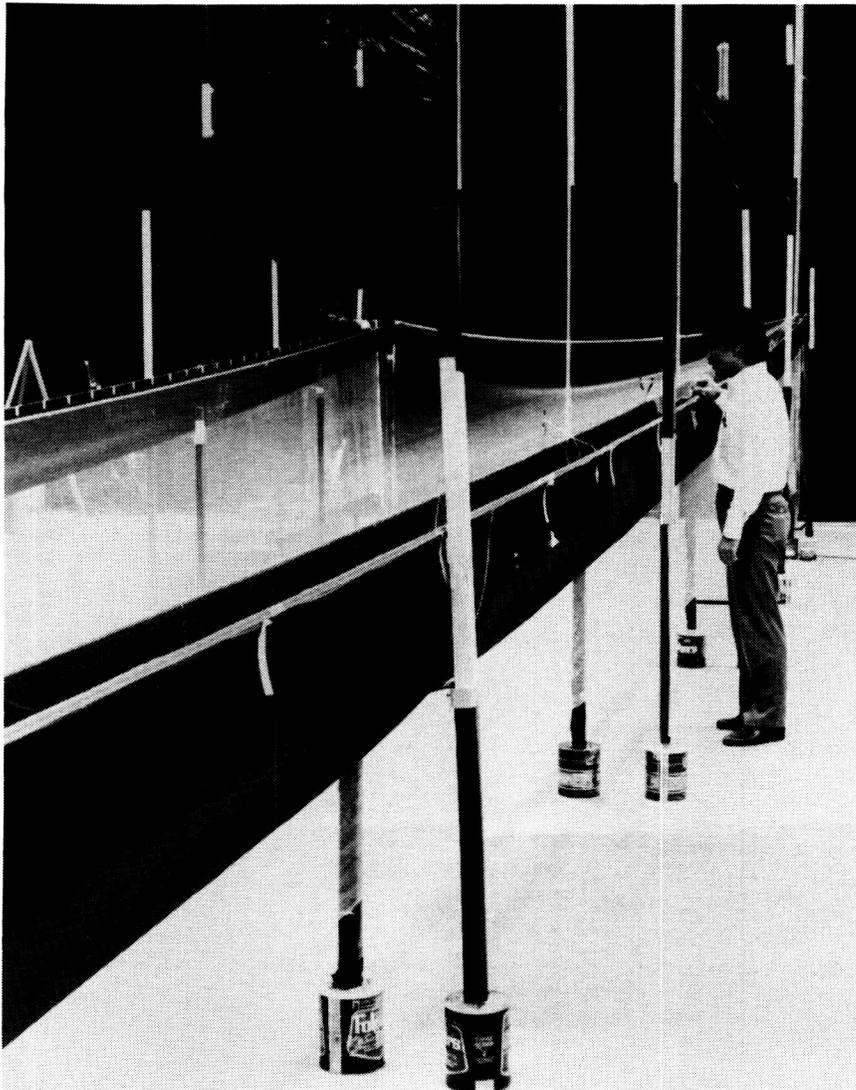


MESH GORE FABRICATION (CONTINUED)



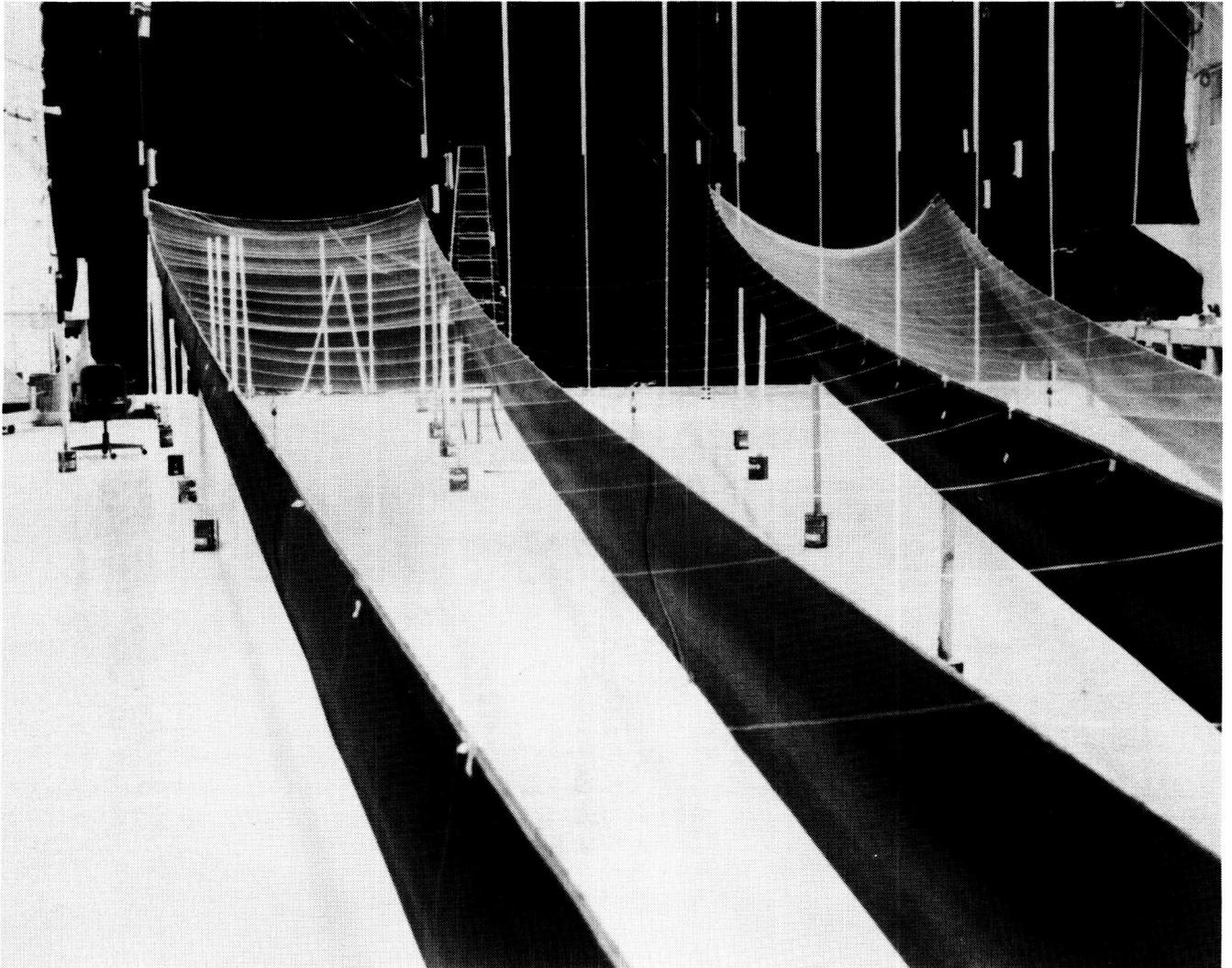
## INITIAL GORE POSITIONING

The mesh gore assembly was positioned for a preliminary check onto the rib assemblies. The rib assemblies were supported using a vertical support stand.



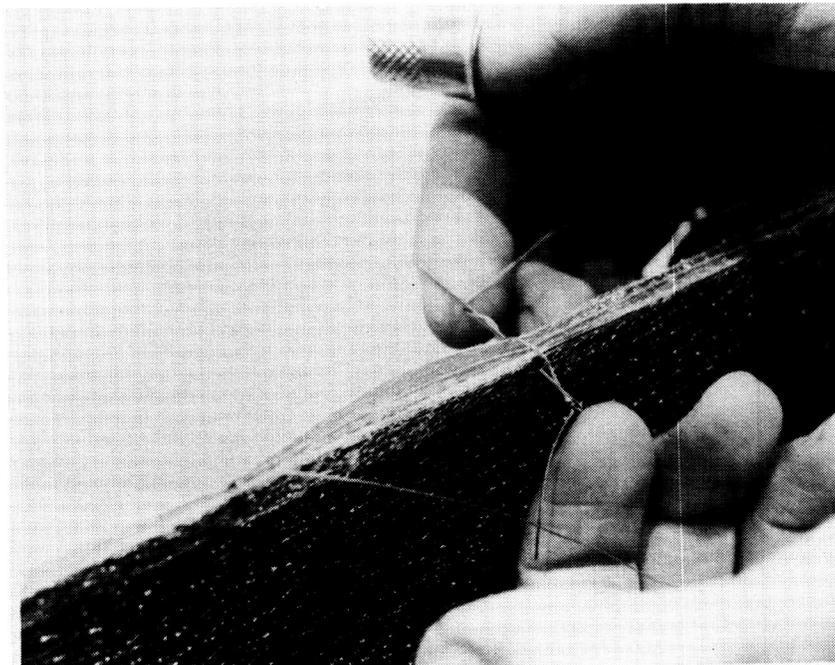
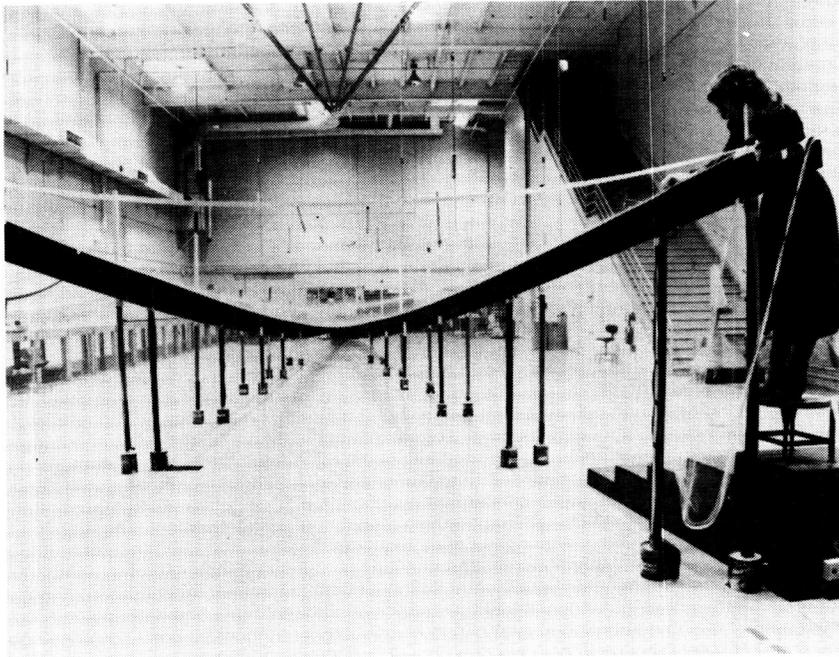
## MANUFACTURING SUPPORT LINES

Manufacturing aids were installed between the rib assemblies to support the mesh gore during final installation.



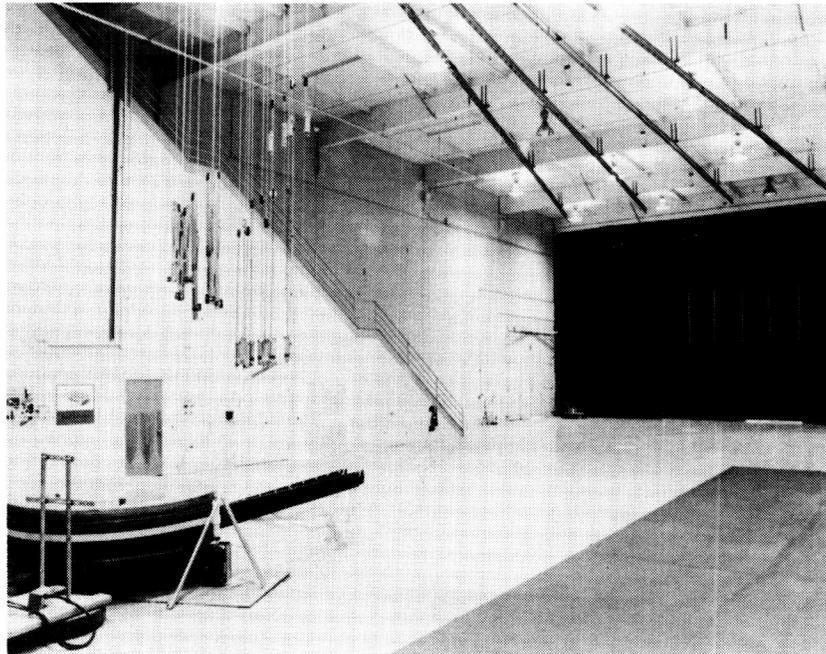
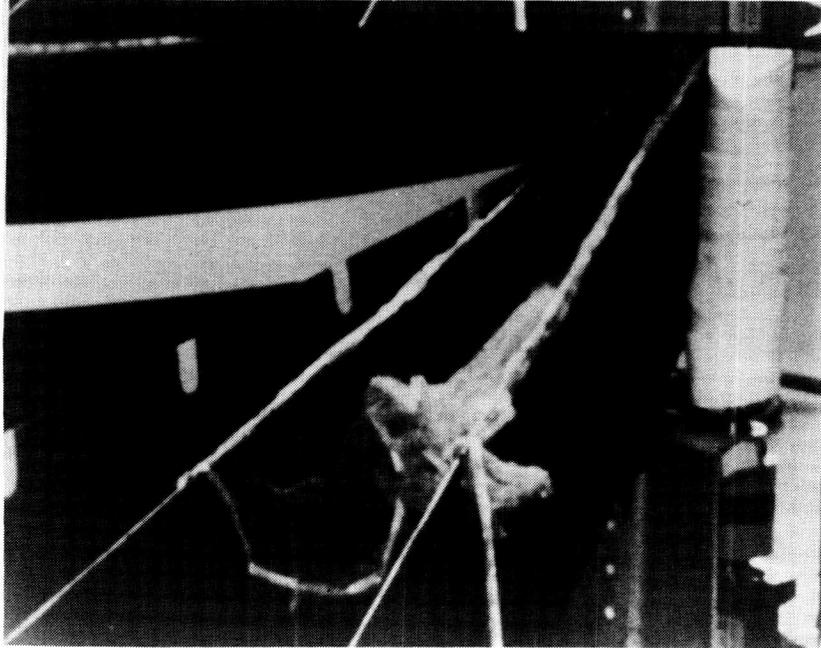
## MESH GORE ATTACHMENT

The ribs were aligned and positioned in the final configuration. The mesh gore was attached to the ribs with stitches through holes previously drilled along the top edges of the ribs. Each stitch was locked in place with a modified clinch knot.



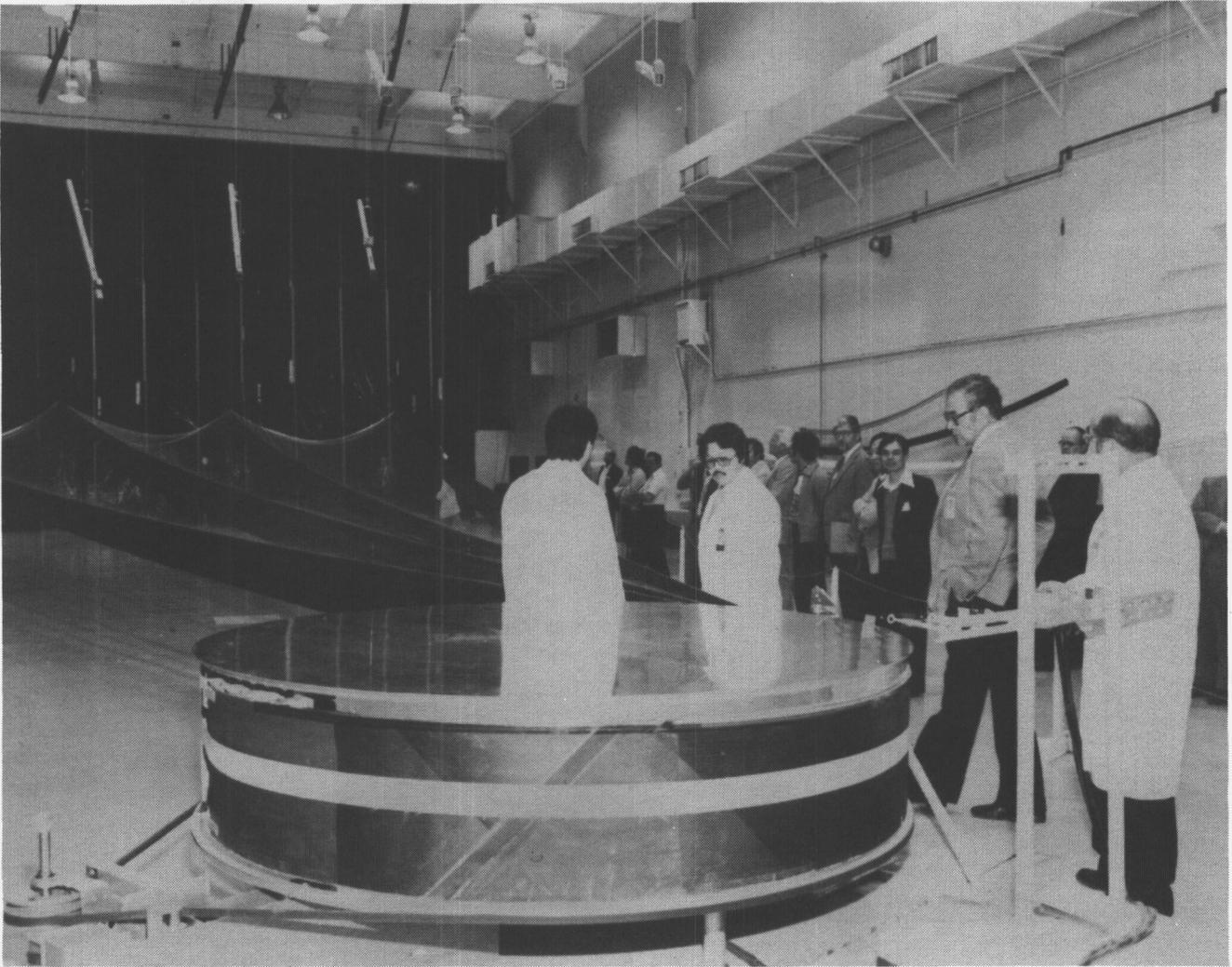
## PRELIMINARY MESH MANAGEMENT STUDIES

Initial studies were conducted with two "used" mesh gores installed on the partial reflector. The mesh gores were stowed in several different ways, including some worst-on-worst configurations. All deployments were successful with no mesh tearing or impairment of rib deployment. For the final deployment with "new" mesh gores, the pleat-type fold (accordian) configuration was selected and was stowed between the rib section during the stowage onto the hub assembly. Again all tests were successful with no mesh damage or impairment to deployment.



## COMPLETION OF DEPLOYMENT TESTS

The four-rib partial reflector proof-of-concept deployment was successfully demonstrated to JPL/NASA/Lockheed and the media on 30 March and 26 April 1984 (see figure below and on the next page).



COMPLETION OF DEPLOYMENT TASKS (CONTINUED)

