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DEVELOPMENT OF THE LENS ANTENNA DEPLOYMENT DEMONSTRATION (LADD) SHUTTLE-ATTACHED FLIGHT EXPERIMENT

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OPERATIONAL SPACE-FED SPACE BASED RADAR SATELLITE ON-ORBIT

Studies conducted over the past decade have shown that Space-Based Radar (SBR) will be a critical element of the U.S. surveillance system by the late 1990's. These studies have narrowed the choice to SBR systems employing space-fed or corporate-fed phased arrays. It is apparent that as stealth technology improves and defense against missile systems becomes viable, the SBR configuration must have growth potential and the capability of being deployed with large apertures to provide surveillance of dim targets. In order to enhance its survivability, it must be flown at high altitudes. It is equally apparent that in order to satisfy these requirements, a lightweight deployable aperture is required.

The Rome Air Development Center (RADC) and the Strategic Defense Initiative Organization (SDIO) have teamed together to provide technology for a deployable lens concept. These studies have addressed the various radar frequencies required for both atmospheric (L-Band; 1.0 - 2.0 GHz) and space (X-Band; 8.2 - 12.4 GHz) surveillance. As a result of these studies lightweight membrane apertures of the various radar frequencies are being developed along with an associated roll-out deployment technique. Figure 1 shows a typical large aperture operational space fed satellite. Utilizing the experience gained from the Solar Array Flight Experiment (SAFE), NASA's Marshall Space Flight Center (MSFC) will manage the development of a space flight demonstration of several of the applicable technologies.

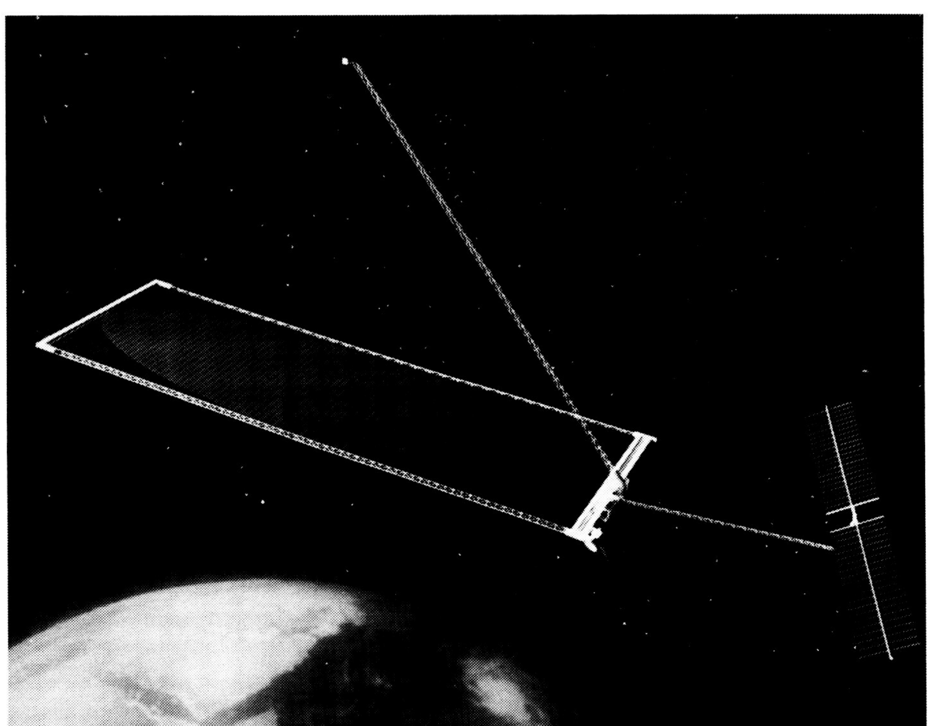

FIGURE 1

DEPLOYMENT CONCEPT FOR LARGE SPACE-FED SPACE BASED RADAR SATELLITE

The deployment sequence of the satellite is illustrated in Figure 2. The satellite is launched in its fully stowed configuration ("A") mounted lengthwise in the shuttle payload bay. Once in low earth orbit it is lifted out of the payload bay and transferred to the appropriate higher orbit via independent booster or space tug. After achieving the appropriate orbit, the satellite is unfolded ("B"), and locked ("C"), and the membrane is deployed by the extension of deployable masts ("D"). Although evident in Figure 1 but not illustrated in Figure 2, deployable masts also erect the feed used to illuminate the aperture and the solar panels which would be used on satellites of certain radar frequencies. As the two halves of the membrane are deployed a center seam which serves as an RF barrier is automatically formed unifying the ground plane into a single large aperture. When fully deployed ("E") the satellite is stabilized by small ion thrusters located at its corners. These control inputs are extremely small and do not cause structural or membrane responses that significantly affect radar operation. The need for large and accurate control inputs to repoint the aperture is eliminated by the inherent electronic beam steering of a phased array radar.

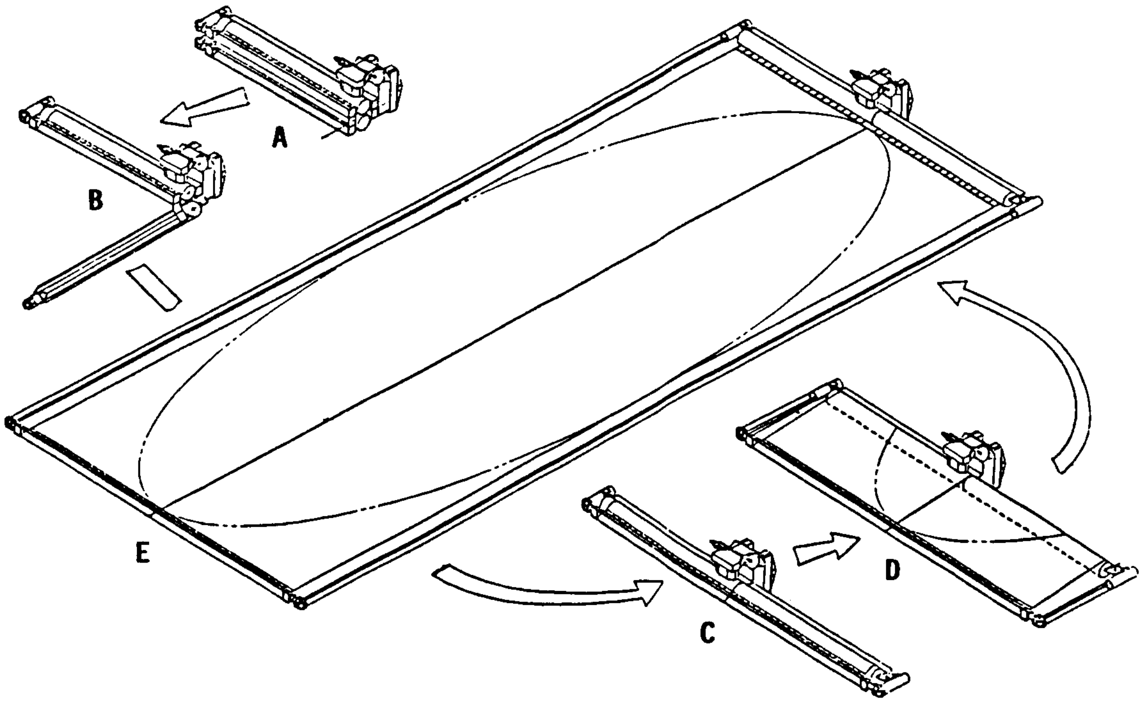

FIGURE 2

LADD EXPERIMENT DEPLOYED IN THE SHUTTLE CARGO BAY

An essential and significant early step towards making these large space-fed SBR satellites a reality is the Lens Antenna Deployment Demonstration (LADD) project that is being sponsored by the Strategic Defense Initiative Organization (SDIO) and NASA, managed by RADC and MSFC and developed under contract by the Space Systems Division of Grumman Corporation. The LADD is a scaled version of the operational satellite which will be mounted on a standard Material Science Laboratory (MSL) pallet, carried into orbit aboard the shuttle and deployed in the orbiter bay (see Figure 3). It is to be heavily instrumented to provide appropriate thermal and dynamics data on critical components. LADD is a single axis roll-out deployable/retractable test article with a membrane which is representative of an X-band antenna. Its structural and mechanical concepts are, however, equally applicable to membranes tailored to other radar frequencies. The primary elements of LADD are a drum, two deployable side-masts/canisters, an end beam and an 8 ft. x 20 ft. membrane populated by approximately 5000 dummy radar modules. The membrane dimensions were established by the width of the shuttle cargo bay and the lateral mounting of the LADD experiment.

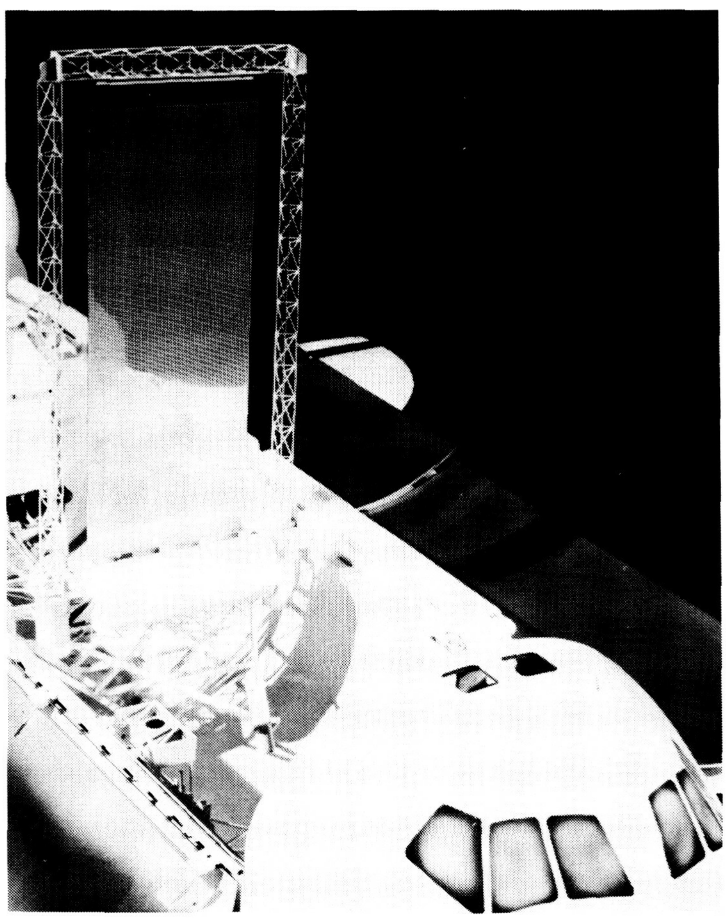

FIGURE 3

LADD STOWED CONFIGURATION (VIEW LOOKING FORWARD)

In the stowed (lift off and landing) configuration the membrane is rolled up on the drum and the side-masts are retracted into their canisters as shown in Figure 4. The experiment has been designed to fit within a 6 inch shuttle bay dynamic envelope.

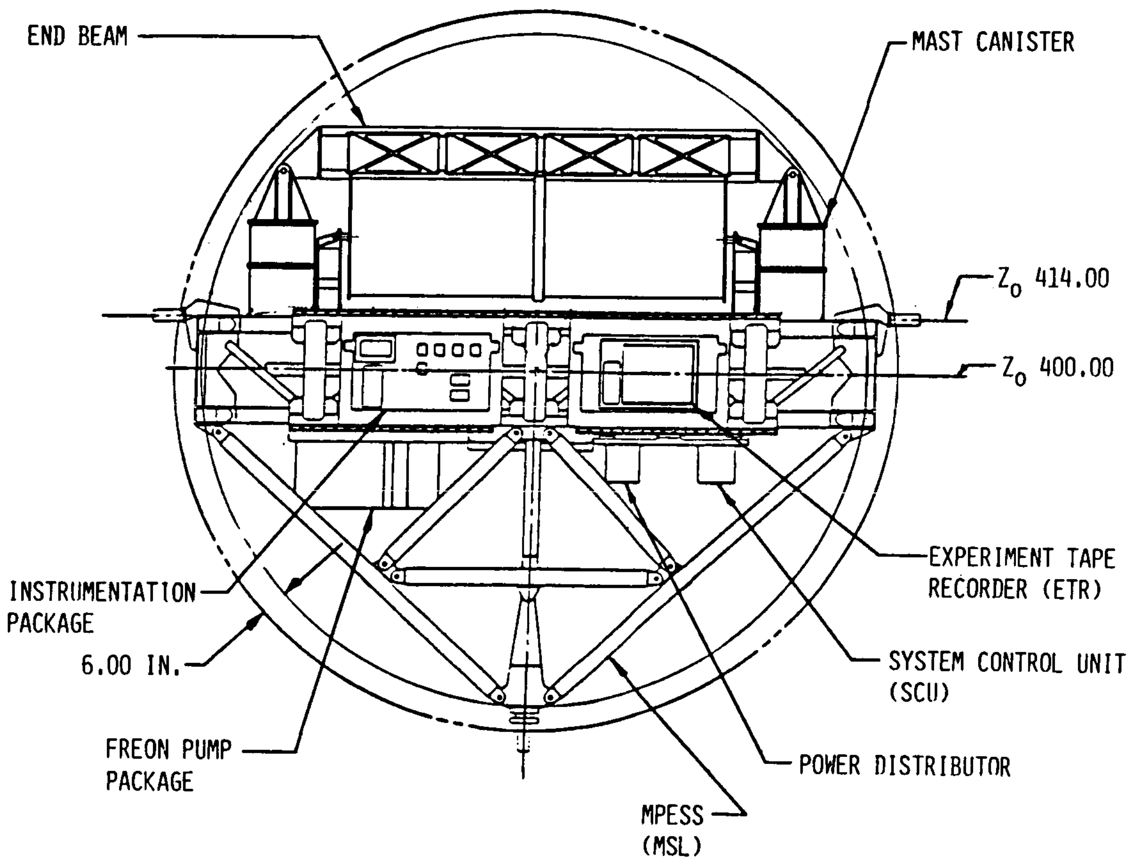

FIGURE 4

LADD DEPLOYED CONFIGURATION (VIEW LOOKING AFT)

In the deployed configuration the side-masts and aperture are extended out of the canisters and off of the drum respectively (Reference Figure 5).

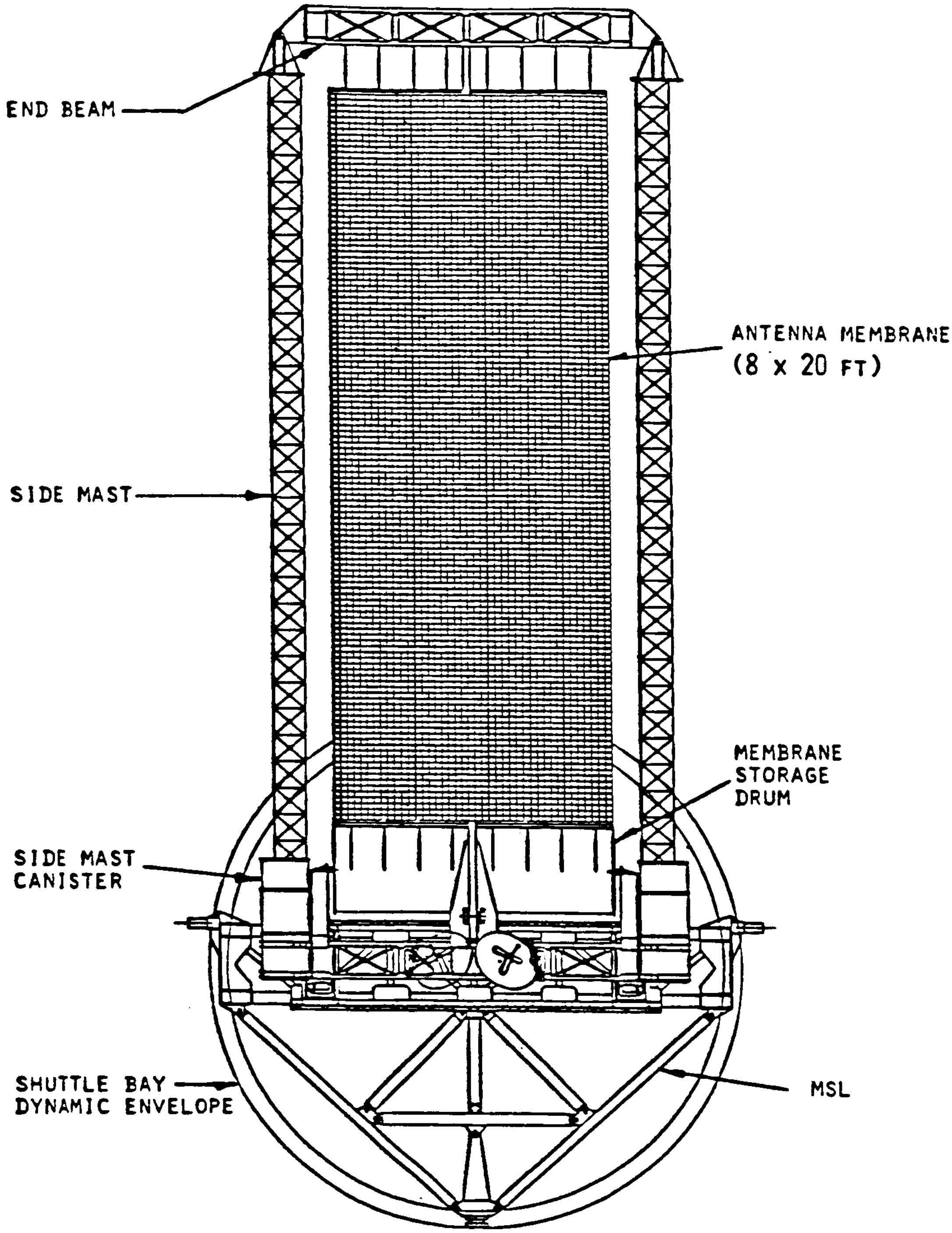

FIGURE 5

OBJECTIVES OF THE LADD PROGRAM

The primary objective of the LADD Program is to develop a technology demonstration test article that can be used for both ground and flight tests to demonstrate the structural and mechanical feasibility and reliability of the single-axis roll-out SBR approach. As designed, the LADD will essentially be a generic structural experiment which incorporates all critical technology elements of the operational satellite and is applicable to a number of future antenna systems. However, to fully determine its design integrity for meeting the lens flatness and constant geometry requirements in a zero "g" environment under extreme thermal conditions, the LADD must be space flight tested. By accurately surveying the structure under varying conditions the membrane tolerance-holding capabilities of the structure will be demonstrated. The flight test will provide data to verify analytical tools used to predict thermal and structural behavior. Most important, the experiment will provide an initial indication of structural damping in a zero "g" vacuum environment. The recently completed Solar Array Flight Experiment (SAFE) showed orbital damping greater than that experienced during ground testing. From the experience and the information obtained from LADD it is hoped that designs can be confidently extrapolated to operational satellites with apertures in the 20 m by 60 m size range.

The specific objectives to be achieved during the flight test include:

- Demonstration of system reliability through the repeated full deployment and retraction of the membrane at temperature extremes representative of an operational satellite.

- Demonstration of the membrane center seam integrity and reliability through its repeated formation and separation and the firing of orbiter primary control system thrusters during dynamic tests with the membrane deployed.

- Measurement of membrane flatness in a static mode and at temperature extremes representative of an operational satellite to verify compliance with radar system requirements.

- Verification of the integrity of the membrane launch support system (stowed mode) for sustaining launch and landing loads.

- Verification of dynamic and thermodynamic models and analyses of LADD to provide confidence in their extrapolation to, and use on large structures associated with operational satellites.

- Determination of structural and membrane damping coefficients on-orbit for use in future analyses.

OBJECTIVES OF THE LADD PROGRAM

OVERALL: DEVELOP TECHNOLOGY DEMONSTRATION TEST ARTICLE INCORPORATING KEY ELEMENTS OF SINGLE AXIS ROLL-OUT DEPLOYMENT APPROACH

SPECIFIC:

- DEMONSTRATE DEPLOYMENT/RETRACTION SYSTEM RELIABILITY
- DEMONSTRATE CENTER SEAM INTEGRITY AND RELIABILITY
- MEASURE DEPLOYED MEMBRANE FLATNESS (STATIC TEST)
- VERIFY INTEGRITY OF MEMBRANE LAUNCH SUPPORT SYSTEM
- OBTAIN DATA TO VERIFY DYNAMIC AND THERMODYNAMIC MODELS AND ANALYSES
- DETERMINE STRUCTURAL AND MEMBRANE DAMPING ON-ORBIT

FIGURE 6

ENGINEERING APPROACH

The LADD is being developed essentially as a protoflight system. A single article is being developed for both functional ground test and checkout and the flight experiment. All significant structural and mechanical features of the operational single axis roll-out antenna concept will be incorporated in the LADD design and ground tested. No changes in the design or hardware are envisioned between the ground and flight tests except those, if any, that might be dictated by the results of the ground tests.

In the engineering approach taken a number of design studies and analyses are being conducted prior to the completion of the design phase. These studies and analyses, which include a shuttle integration compatibility assessment and orbiter coupled loads analysis, are intended to ensure that the configuration selected will be shuttle compatible and that it will have the desired natural frequency to prevent cross coupling with orbiter frequencies and meet the lift-off, on orbit and landing loads criteria with adequate margins of safety.

- UTILIZE PROTOFLIGHT SYSTEM DEVELOPMENT CONCEPT
  (SINGLE TEST ARTICLE FOR GROUND AND FLIGHT TESTS)
- INCORPORATE ALL SIGNIFICANT FEATURES OF OPERATIONAL SATELLITE
- CONDUCT ALL ESSENTIAL STUDIES AND ANALYSES EARLY IN DESIGN PHASE TO:
  - ENSURE SHUTTLE COMPATIBILITY
  - PROVIDE ACCURATE DESIGN LOADS
  - GUARANTEE SUBSTANTIAL MARGINS OF SAFETY ARE ACHIEVED
- CONDUCT EXTENSIVE GROUND TESTS TO THOROUGHLY QUALIFY HARDWARE
- MODIFY HARDWARE ONLY WHEN DEEMED NECESSARY BY GROUND TEST RESULTS

FIGURE 7

The LADD primary structural and mechanical components are identified in Figure 5. The LADD membrane, which is approximately 20 ft. long and 8 ft. wide, has a single layer laminated ground plane which is made of two panels, one on each side of the centerline. Each panel is made from two 2-ft wide sections that are permanently connected by thin metallized strips. The two panels are automatically mated during deployment by a center seam. These panels form the aperture that contains approximately 5,000 dummy transmitter/receiver (T/R) modules. The dummy modules (Figure 8) are designed and appropriately coated so that through passive solar heating their surface temperatures approximate those predicted for "live" x-band modules. Each module is mounted to the ground plane with two hollow rivets.

The ground plane Power Distribution System (PDS) for providing power to each T/R module will be simulated by a method that is similar to that which will be used in a live radar. In the LADD experiment the PDS will be used to transmit instrumentation signals about the membrane. The membrane is supported from the end beam by lanyards and from the drum by a series of constant force springs. These springs impart a constant pretension to the membrane at all times in the deployed state.

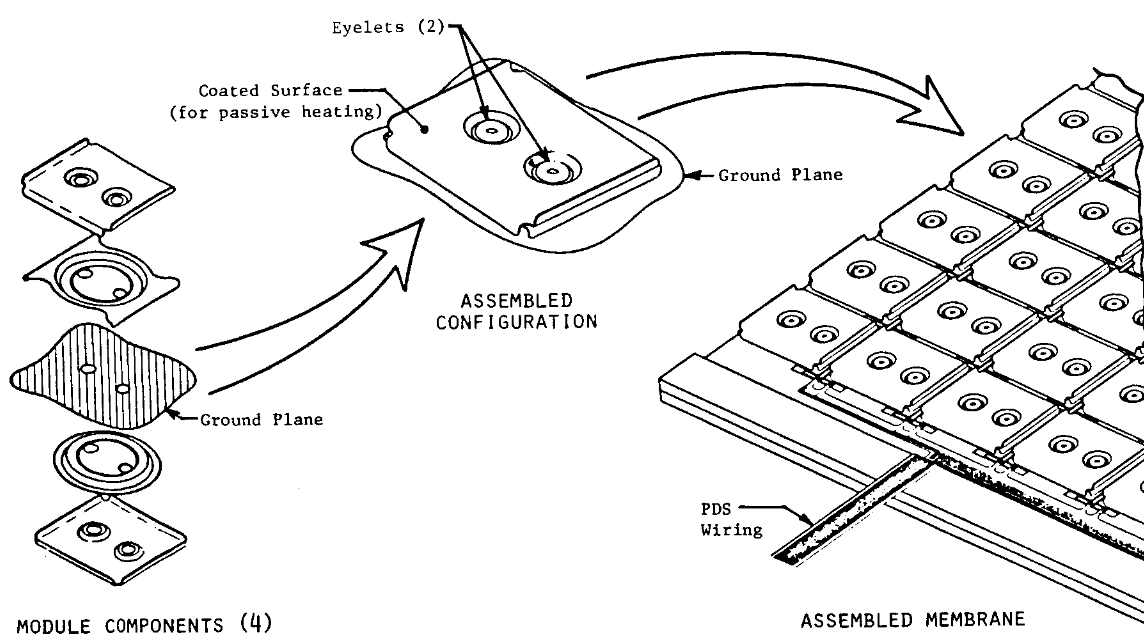

FIGURE 8

LADD END BEAM CONFIGURATION

The end beam that supports the membrane is constructed of 1 in. square boxed aluminum extrusions and is the common link or bridge structure between two coilable (deployable/retractable) fiberglass masts. These masts are similar to the one that was successfully flown on the Solar Array Flight Experiment (SAFE) on the space shuttle Discovery in September 1984.

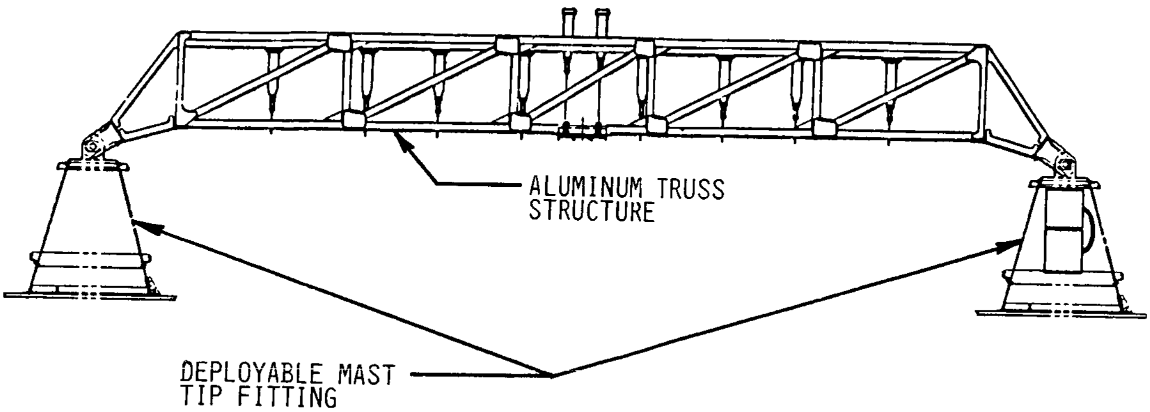

FIGURE 9

DEPLOYABLE SIDE MASTS

The deployment of the membrane is accomplished through the extension of the side masts. Each mast consists of three continuous fiberglass longeron members connected by a triangle of fiberglass batten members at specific, equally spaced locations along the longerons (see Figure 10). The region between the battens is called a "bay". The bay length is a significant factor in determining the mast local buckling strength. The LADD masts have been selected with sufficient strength to allow vertical deployment in a 1 "g" environment. Three pairs of fiberglass rods or stranded stainless steel wire diagonals connect the intersections of the battens and longerons between adjacent bays. Rollers are located at the outside of all three longerons at each batten location. The rollers are part of apex fittings that are permanently attached to the longerons and support the battens and diagonals. Detail "A" of Figure 10 shows the geometrical relationship between the longerons, battens and diagonals at a typical apex fitting.

The masts are retracted by coiling the longerons in torsion and stowing them in the bottom of the canisters. Deployment is accomplished by allowing the coiled (stowed) longerons to uncoil and straighten in a controlled manner. Both deployment and retraction is accomplished by rotating an elevating nut which has internal threads that simultaneously engage the rollers on each of the three longeron apex fittings associated with a batten attachment. During deployment, as the elevating nut rotates the rollers are pulled up through the threads and the coils of longeron are allowed to straighten. Reversing the direction of elevating nut rotation drives the rollers back into the canisters and forces the longerons to resume their coiled/retracted configuration. In the LADD experiment the deployment and retraction of the two masts will be synchronized to prevent asymmetry.

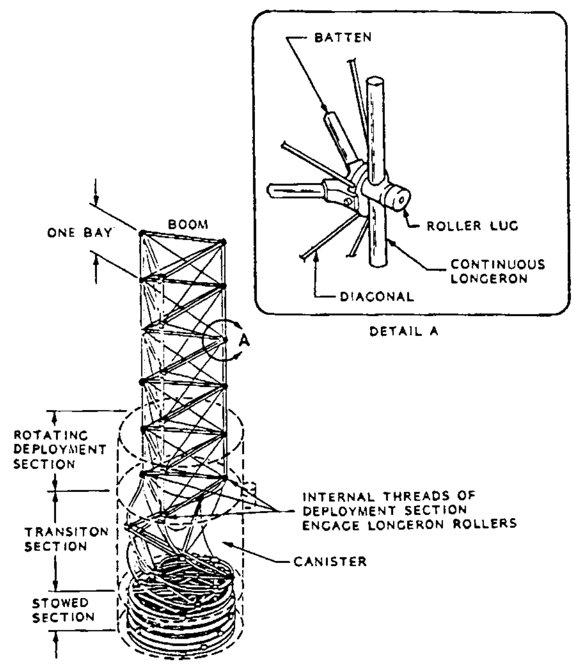

FIGURE 10

DRUM AND DRUM SUPPORT TRUNNIONS

During the deployment and retraction of the masts the LADD membrane is being unwound and rewound respectively from a 29-inch diameter, continuous 8 ft. long drum. The drum has an aluminum skin supported internally by stringers and ring frames. There is a flange at the center of the drum that duplicates the end rims of a folding drum envisioned in an operational system. The membrane launch support system is built into the drum skins to support the first layer of modules and the membrane during launch and landing. Each subsequent layer of membrane is supported by the modules of the previous wrap and, when fully stowed, an additional torque is applied to the drum and the drum is locked.

The drum is supported by trunnion fittings at each end that are fitted with rolling element and spherical bearings. The trunnions are tapered aluminum beams that are, in turn, connected to the drum support beam which is similar in construction to the end beam. The drum support beam has four "bathtub" fittings at each end that attach to the sides of the mast canisters. The drum support beam also supports the center seam mechanism.

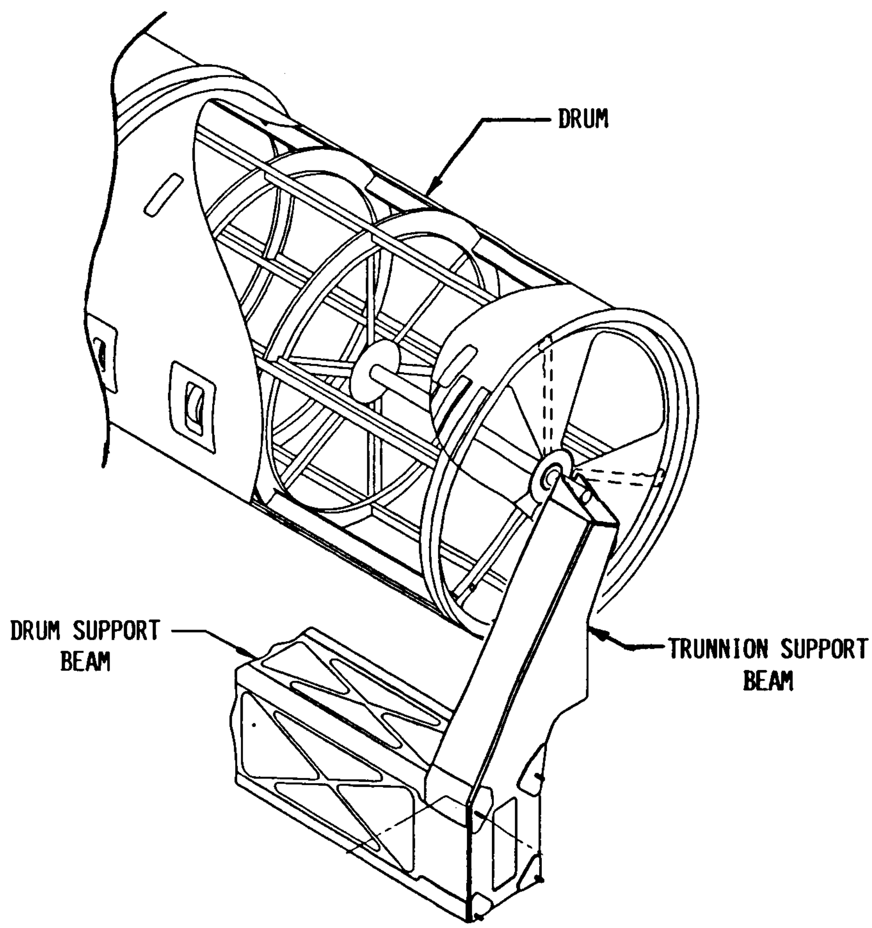

FIGURE 11

The center seam, although not required on the 8 ft. wide LADD membrane, is being incorporated and is a key element of the technology demonstration. The center seam must provide structural integrity, an effective RF barrier, durability and appropriate life in terms of formation/separation cycles and yet fit within the limited space available (approximately 1/4 in.) between modules in the densely populated x-band membrane. A center seam configuration possessing all of these characteristics has been developed and tested. Figure 12 shows an engineering development test rig with an abbreviated width (5 module wide) membrane which forms two parallel center seams 20 ft. long. Center seams of virtually unlimited length can be fabricated using the processes developed by Grumman.

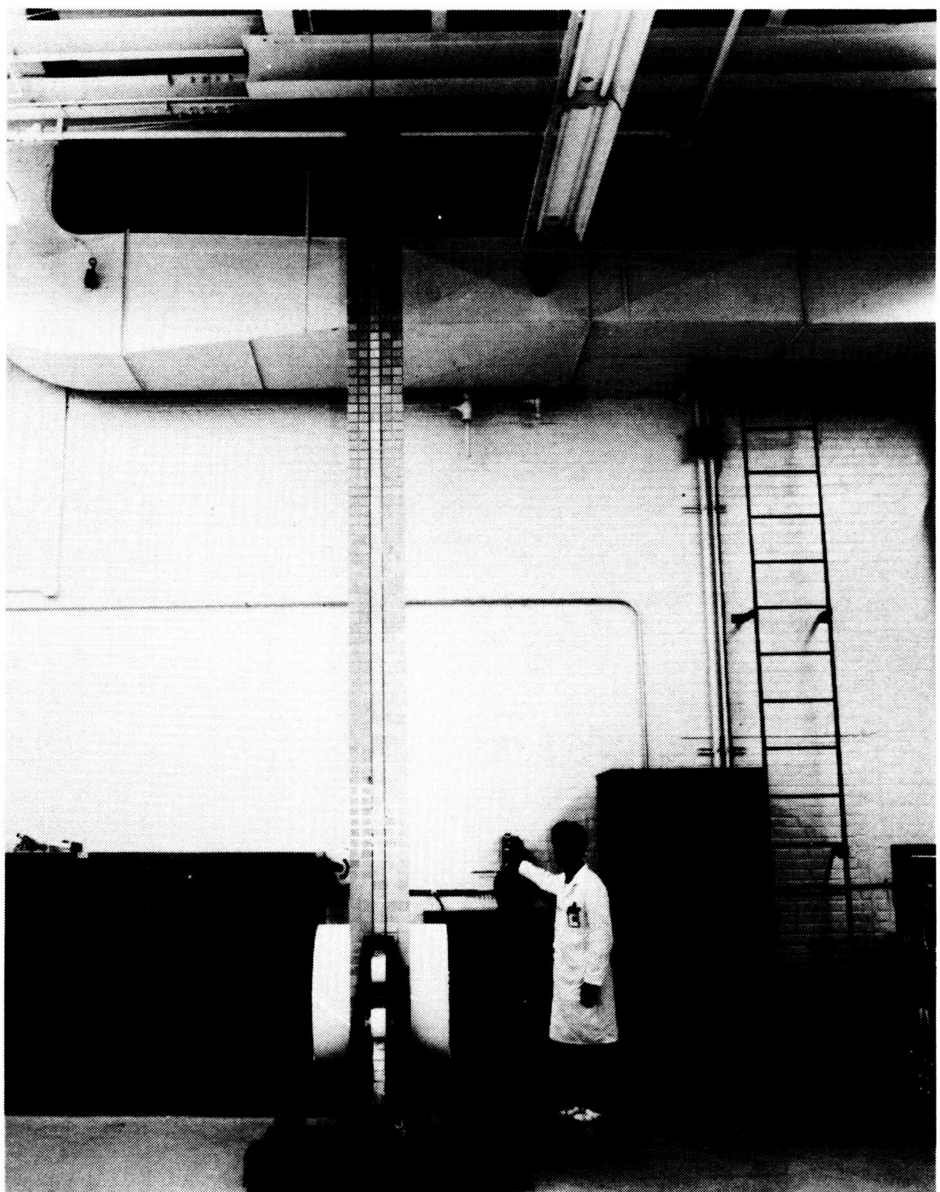

FIGURE 12

SEPARATION SYSTEM MECHANISM

The LADD structure is mounted to an adapter plate which is itself mounted to the MSL pallet. At the interface between the LADD drum support beam and adapter plate on both the port and starboard sides are redundant, two failure tolerant separation mechanisms (see Figure 13). These separation systems would be activated in the unlikely event that a failure of LADD or shuttle equipment prevents the retraction of safe stowage of the experiment. Should such an event present a flight safety problem, the Remote Manipulator System (RMS) would lift the experiment out of the payload bay and jettison it prior to re-entry.

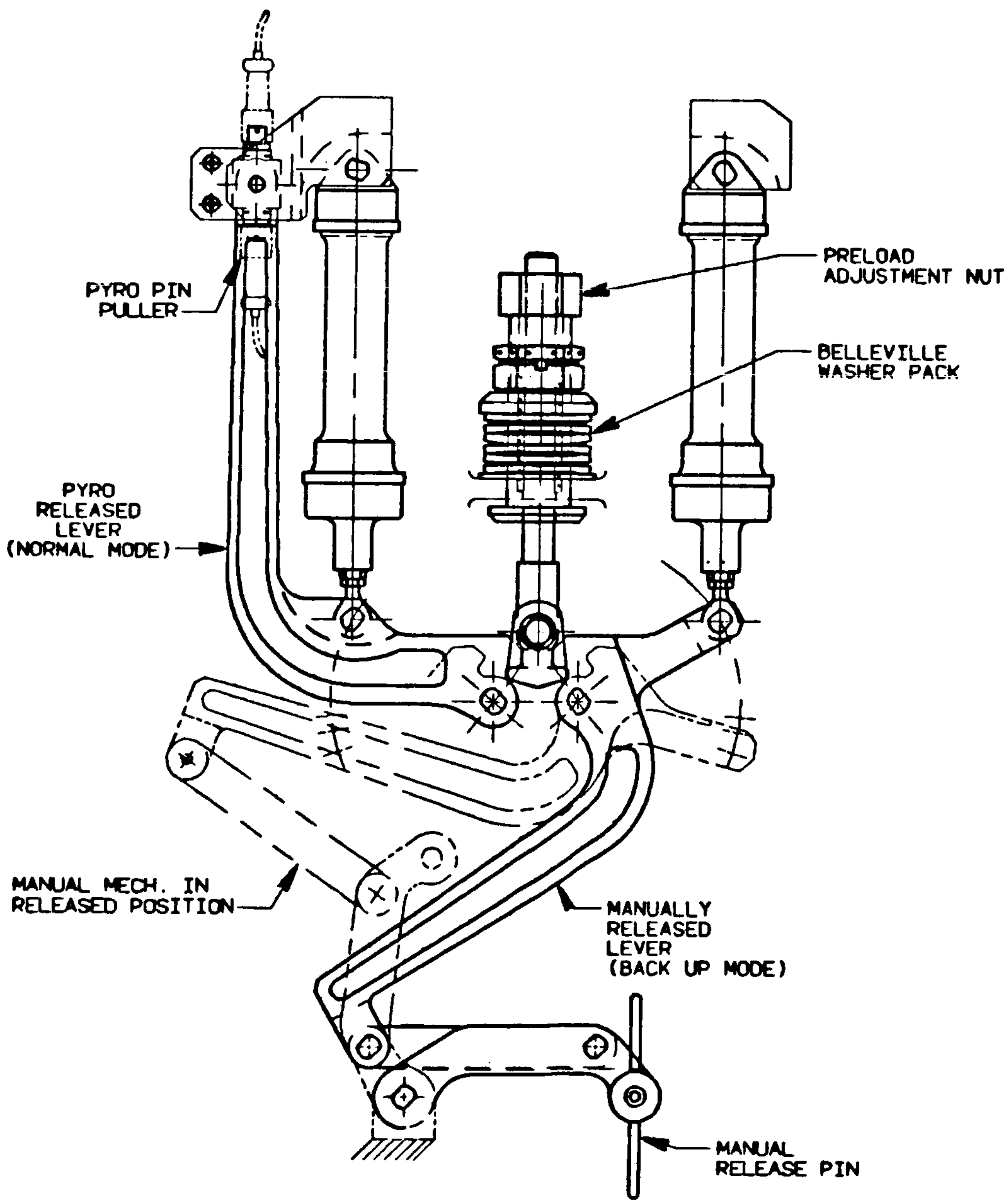

FIGURE 13

VERIFICATION OF DYNAMIC ANALYSES

Detailed finite element models of the LADD have been developed and comprehensive finite element analyses (FEA's) are being conducted for the ground test configuration attached to the MSL. The opportunity to perform meaningful correlation studies will be afforded when modal surveys are performed, at both Grumman and MSFC. These tests will also provide significant modal damping information that will be useful in final planning of the flight test program.

Flight testing will provide the opportunity to perform correlation studies to ultimately determine if the FEA's can accurately predict behavior of a single-axis roll-out satellite membrane. During flight testing membrane modal shapes will be recorded with the shuttle CCTV cameras. Dynamic inputs will be provided by firing specific orbiter primary RCS engines in a predetermined sequence. Determination of modal damping will provide important information with regard to the design of an SBR control system. Comparison of flight and ground test results for the LADD structure could also be helpful in resolving any anomalies.

- DETAILED FINITE ELEMENT MODELS OF STOWED LADD/MSL DEVELOPED
- BASE DRIVE AND COUPLED LOADS ANALYSES CONDUCTED FOR CRITICAL CONDITIONS
- MODAL SURVEYS OF LADD AND LADD/MSL COMBINATION WILL PROVIDE DATA FOR CORRELATION OF MODELS AND ANALYSES
- BASIC MODEL OF DEPLOYED MEMBRANE ALSO DEVELOPED
- DEPLOYED MODEL USED TO DEFINE ORBITER RCS FIRINGS FOR ON-ORBIT MODE SURVEYS
- ON-ORBIT DYNAMIC TESTS WILL PROVIDE ESSENTIAL MODAL DAMPING INFORMATION FOR FUTURE SBR SATELLITE DESIGNS

FIGURE 14

GSI CAMERA AND GAS CAN CONFIGURATION

The LADD is designed to meet the tolerances imposed by radar system requirements. The in-plane thermally-induced deflections can amount to a change in length of up to .04% for the long lens aperture. In an operational satellite this motion will be compensated for electronically. The out-of-plane flatness requirement for an x-band 8 ft. by 20 ft. membrane has also been determined. The membrane will be measured in the as-built configuration to establish baseline dimensions. After repeated deployments and retractions, measurement data will be collected for the membrane while on-orbit to determine if any permanent distortions have occurred.

The measurement of the membrane flatness and geometric stability will be determined with the use of three Geodetic Services Incorporated (GSI) photogrammetric cameras. Since existing cameras were not designed to be operated in a vacuum they will be contained in Get Away Special (GAS) cans (Figure 15) filled with presurized nitrogen.

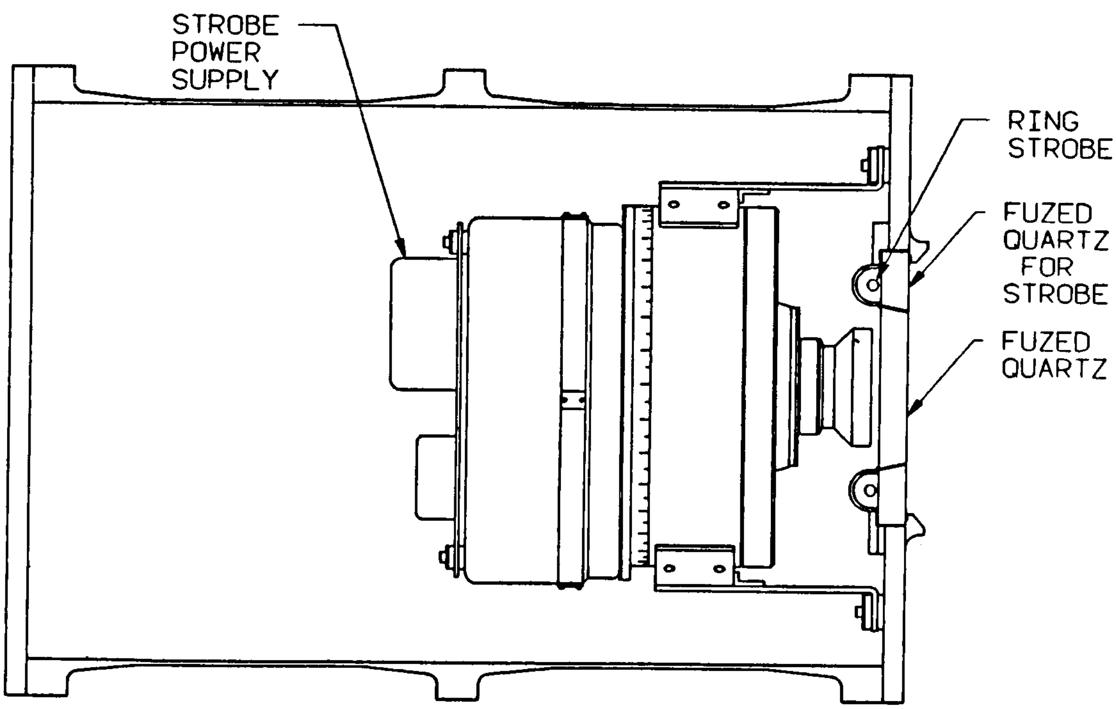

FIGURE 15

GENERAL CONFIGURATION - LADD MPESS CAMERA PALLET

The three cameras are carried in the shuttle on a Mission Peculiar Experiment Support Structure (MPESS) mounted forward of the LADD MSL pallet in the payload bay (Figure 16). Two of the cameras will be attached to the MPESS, and the third will be mounted on the previously flown Release/Engage Mechanism (REM) which is being furnished by MSFC.

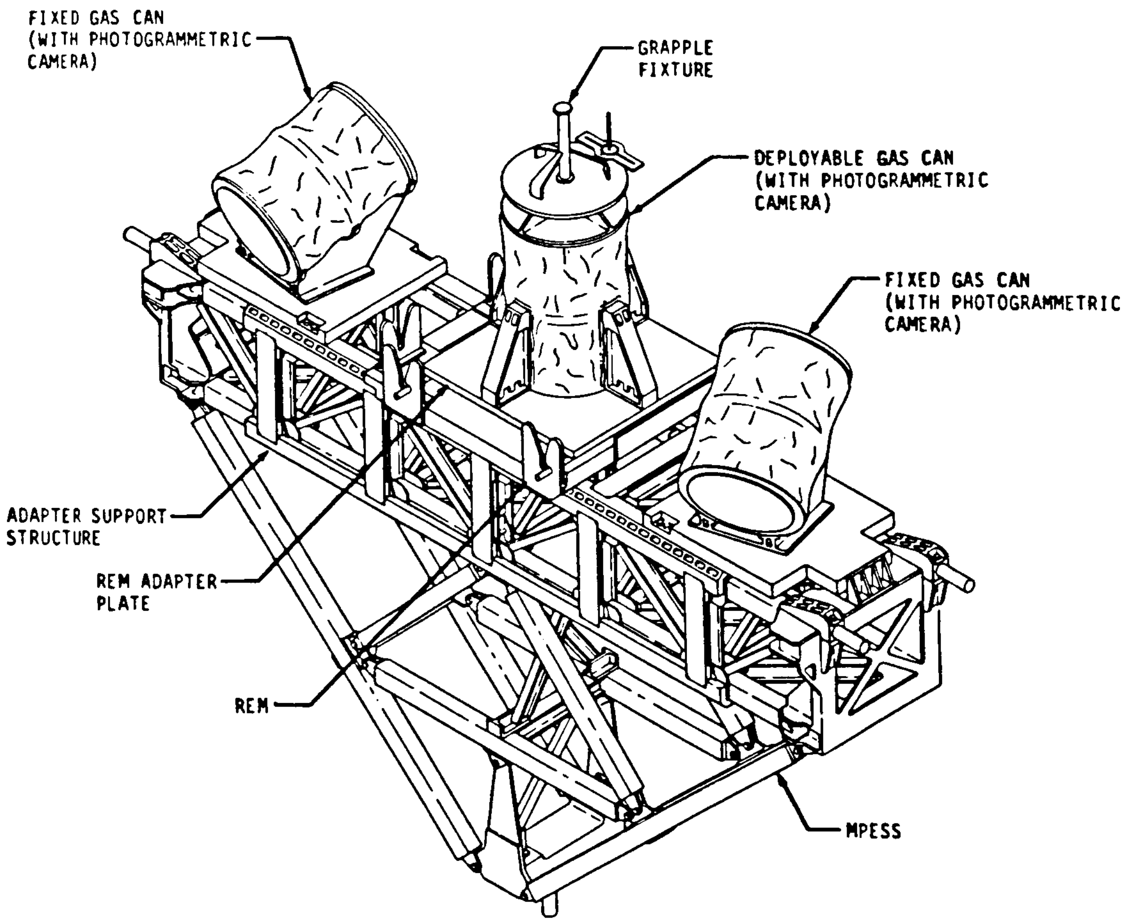

FIGURE 16

PHOTOGRAMMETRIC CAMERA TRIANGULATION

For photogrammetric measurement the REM mounted camera will be deployed and held by the RMS in such a position as to provide triangular viewing coverage of the membrane (Figure 17). Small photogrammetric targets will be mounted on the modules at specific locations on the membrane. Using analytic photogrammetry and calibration procedures that have been sucessfully employed in ground tests membrane flatness and geometric stability will be determined.

The deployment/retraction of the LADD and the activation of the three photogrammetric cameras will be commanded through hardwire control from the Payload Specialist station in the aft cabin of the shuttle.

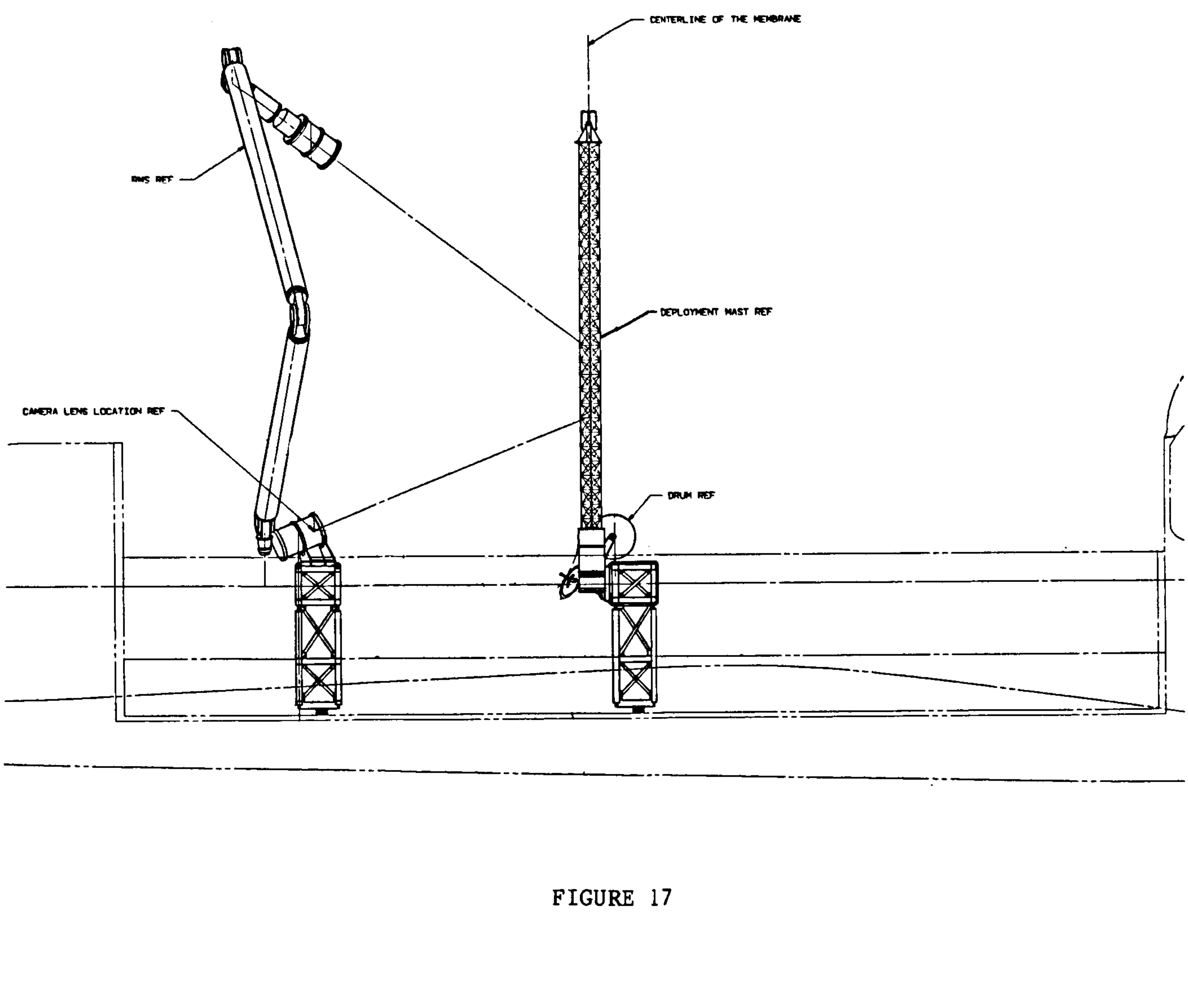

FIGURE 17

LADD PROGRAM MILESTONES

The specific experiment objectives have been published in the LADD Experiment Requirements Document and are currently being converted to a mission time line.

The LADD project recently completed its Preliminary Design Review and is progressing toward a Critical Design Review in early 1987. Figure 18 presents some program milestones as currently scheduled. Phase II of this program including the preflight testing, shuttle integration, flight support and post flight data reduction is currently in the planning stage. The flight date is, of course, not firm as the full impact of the shuttle booster redesign is as yet unknown and the new flight schedule and manifests have not been finalized.

ACCOMPLISHED	
PHASE I CONTRACT AWARD	OCTOBER 1985
PRELIMINARY REQUIREMENTS REVIEW (PRR)	JANUARY 1986
PRELIMINARY DESIGN REVIEW (PDR)	SEPTEMBER 1986
PLANNED	
CRITICAL DESIGN REVIEW (CDR)	JANUARY/FEBRUARY 1987
FABRICATION/INSTRUMENTATION COMPLETED	JANUARY 1988
TESTS/QUALIFICATION COMPLETED	APRIL 1989
DELIVERY TO KSC FOR CHECKOUT AND SHUTTLE INTEGRATION	APRIL 1989
FLIGHT READINESS REVIEW	4TH QUARTER 1989
FLIGHT	4TH QUARTER 1989/ 1ST QUARTER 1990

FIGURE 18