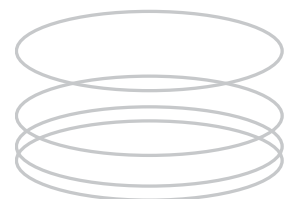# Development of Flight Hardware for a Large, Inflatable-Deployable Antenna Experiment

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DEVELOPMENT OF FLIGHT HARDWARE FOR A
LARGE, INFLATABLE-DEPLOYABLE ANTENNA EXPERIMENT

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Abstract

Large, space-based antennas are needed for a variety of different applications. Since there is no meaningful orbital assembly capability planned at this time, any large space structures will have to be self-deployable. Current concepts for large, conventional, mechanical, self-deployable space structures tend to be very expensive and mechanically complicated. Current antenna-user requirements are so stringent (with respect to the need for very low-cost, high-deployment reliability, low weight, and packaged-volume and usable aperture precision) that new and innovative approaches to accommodate large space structures are needed. Fortunately, a newly developed class of space structures, called inflatable-deployable structures, has great potential for satisfying these stringent user requirements. A concept under development at L'Garde, Inc., for a large, inflatable-deployable antenna represents an excellent example of this new type of structure.

The NASA Office of Space Access and Technology initiated the In-Space Technology Experiments Program (IN-STEP) specifically to accommodate the verification and/or validation of unique, innovative, and high-payoff technologies in the space environment. The potential of the L'Garde, Inc.,

concept has been recognized and resulted in its selection for an IN-STEP experiment. The objectives of the experiment are to verify low cost and light weight by building a 14-meter-diameter flight-quality reflector antenna structure, demonstrate deployable reliability in a realistic environment, and measure the reflector surface precision in a realistic gravity and thermal environment. The approach will utilize the Space Transportation System (STS)-launched, recoverable Spartan spacecraft as the experiment carrier.

The flight-system functional performance requirements originate from the experiment's technical objectives. The design requirements for the flight hardware system are based on a combination of system functional-performance requirements; basic inflatable-structures capability; the L'Garde, Inc., technical data base resulting from the development and launch of a large number of inflatable "decoy type" structures; and the space environment effects on a large, thin-film structure in low earth orbit. The large-space structure/environmental interactions include the effects of atmospheric drag on the attitude stability of the structure, the effects of the orbital thermal environment and atomic oxygen on the thin-film materials, and low-orbit radiation effects on electronic components. Both requirements and environmental effects are specified for each subsystem; e.g., (a) the basic support structure that houses the inflatable structure and the other subsystems and interfaces with the experiment carrier, the Spartan, (b) the inflatable-deployable antenna structure, (c) the inflation system, (d) the surface-measurement system, and (e) the electronic system. For each of the subsystems, this paper will identify and describe the key

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and unique design drivers, the impact of the environmental interactions, the type of analysis used for simulating subsystem performance, the type of developmental testing used for design refinement and validation, the specialized processing, manufacturing and assembly techniques, and description of the final design.

The experiment is being managed by the Jet Propulsion Laboratory. The flight hardware development at L'Garde, Inc., Tustin, California, is currently in Phase C/D, and the experiment is manifested to fly on STS 77 in April 1996 as primary/sharing payload.

Introduction

Space-deployable antennas are needed for a variety of applications that include space-based, very-long-baseline interferometry (VLBI), mobile communications, active microwave sensing, earth-observation radiometry, synthetic aperture radar, spacecraft communications, and DOD space-based radar.' Recent constraints on the availability of resources for these types of applications within NASA, the science community, the commercial sector, and even the DOD, have resulted in stringent user application requirements. Therefore, the real key to accommodating these missions is the development of new concepts for low-cost and mechanically reliable antenna structures. Other important features include low weight, high mechanical-packaging efficiency, usable aperture precision, and long-term dimensional stability. Realistically, however, meaningful demonstrations of innovative concept capabilities will have to be accomplished to attract any kind of serious user interest.[2]

A relatively new and unique concept for an inflatable-deployable spice antenna structure that has tremendous potential for accommodating such stringent user requirements is under development by L'Garde, Inc., Tustin, California.[1,3] In fact, serious user interest has resulted in the selection of this concept for a NASA In-Space Technology Experiments Program (IN-STEP) space-based experiment. This class of experiments is based on demonstrating and evaluating the performance of promising concepts with low-cost flight hardware. The experiment objectives are selected specifically to validate antenna-user criteria and to demonstrate the development of large, flight-quality hardware for a low-cost, high mechanical-packaging efficiency, low weight, high deployment reliability, usable reflector-surface

precision, and thermal stability in a realistic environment.

The experiment is currently in the final stage of flight-hardware assembly and qualification testing. It is manifested to be flown on STS 77 in late April 1996. This paper describes the design of the experiment flight hardware and identifies the key issues for each of the subsystems that comprise the experiment system. The information contained in this paper and in References 1 and 2 is intended to provide a complete summary of the experiment justification, technical approach and flight hardware.

Experiment-System Performance Requirements

The experiment-system functional requirements are based on the experiment objectives and the inflatable-structures concept capability, constrained by the NASA experiment resources available and the capability of the experiment carrier, the Spartan (Figure 1). The antenna structural configuration is based on the L'Garde, Inc., basic inflatable-antenna concept. The 14-meter-diameter reflector size is based on an extrapolation of the 9-meter baseline structures data base and the current size limit for manufacturing capability at L'Garde, Inc. Moreover, this structure can be accommodated by Spartan, and it is large enough to be used for real applications, such as VLBI and commercial mobile communications. The surface-precision goal of 1 mm rms on orbit is based on the current analytical performance projections, manufacturing, assembly, and alignment capability at L'Garde, Inc. Validation and characterization of the deployment sequence will be done on orbit, which provides a realistic operational environment. High mechanical-packaging efficiency will be demonstrated by stowing the inflatable structure in a small canister. The inflight single-orbit measurement of surface precision and its thermal stability will provide a measurement of the concept value for different potential applications.

Qualification of the experiment's hardware is being accomplished by both analysis and test for compliance with functional performance and STS safety requirements.

Subsystem Functional Requirements

The experiment-subsystem functional requirements are driven by the system functional requirements, with design parameters bounded by the
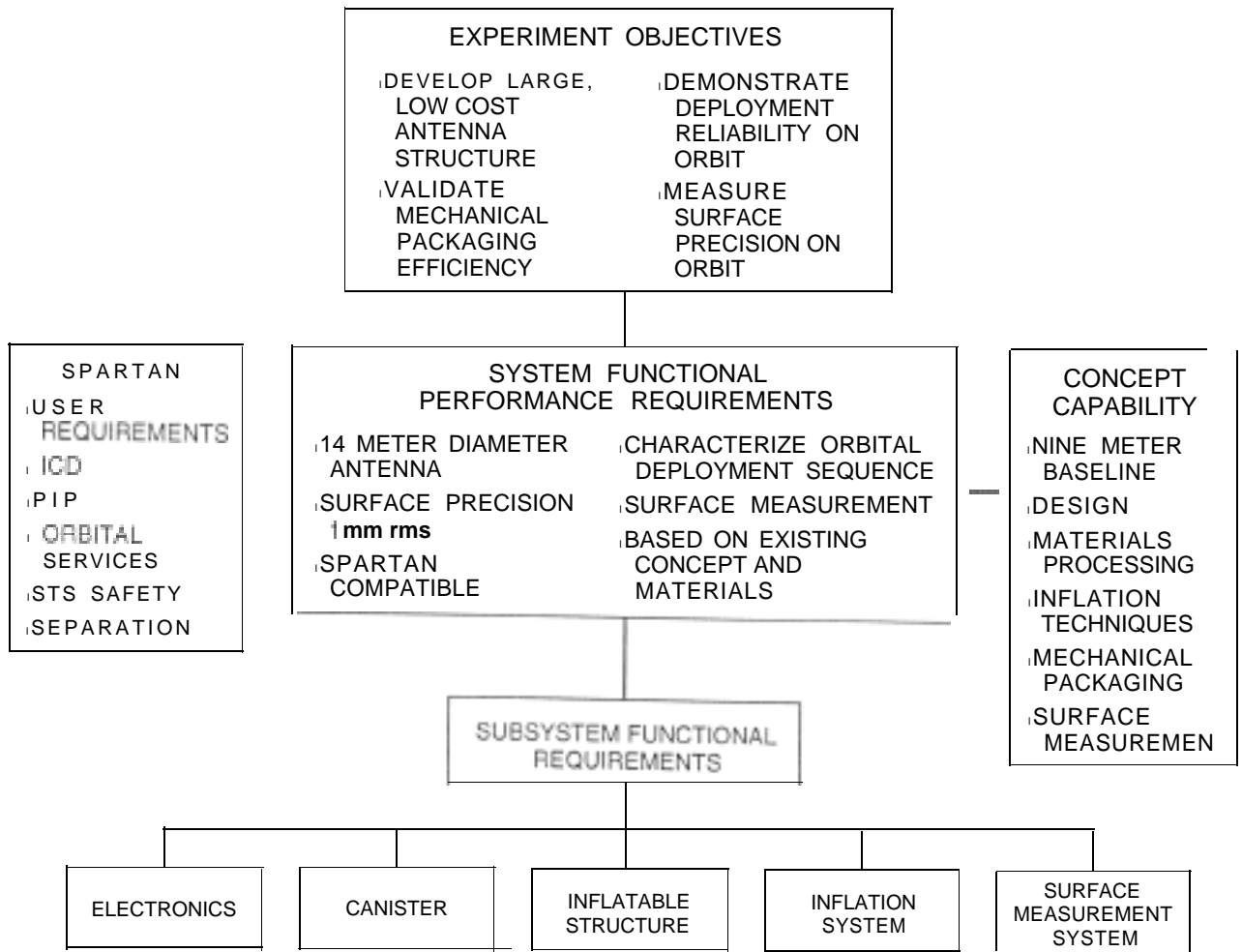
Fig. 1. Experiment Design Requirements

L'Garde, Inc., flight data base for inflatable structures and the environmental-interaction effects on the experiment hardware (Figure 1). The subsystems needed to accommodate the experiment include (a) the inflatable structure, (b) the canister or bus structure, (c) the inflation system, (d) the surface-measurement system, and (e) the electronic system (Figure 2). The combination of these subsystems represents the simplest approach for satisfying the system functional requirements. The design and performance of the actual flight hardware will be based on how well the subsystem functional requirements were satisfied. The key design drivers, the types of analysis used, the functional developmental testing, and pictures of the final designs will be discussed in the appropriate subsystem sections of this paper.

Inflatable Structure

The subsystem functional requirements for the inflatable structure are given by Table 1. The antenna configuration is an off-axis parabolic reflector structure consisting of (a) a 14-meter-diameter, multiple-gore reflector structure and a transparent canopy (which is a mirror shape of the reflector) to maintain gas pressure on orbit, (b) a torus structure that supports the reflector/canopy circumferentially, and (c) three 28-meter-long struts that interface the torus structure with the canister which is located at the center of curvature of the reflector to accommodate operation of the surface-measurement system.

Reflector

The major challenge is to design and fabricate a 14-meter-diameter, multiple-gore reflector structure with an orbital surface precision on the order of 1 mm rms and with enough reflectivity to accommodate orbital operation of the Surface Accuracy Measurement System (SAMS). The system reflector-gore geometry is determined by the L'Garde, Inc., FLATE code, which uses the desired orbital-membrane configuration, its
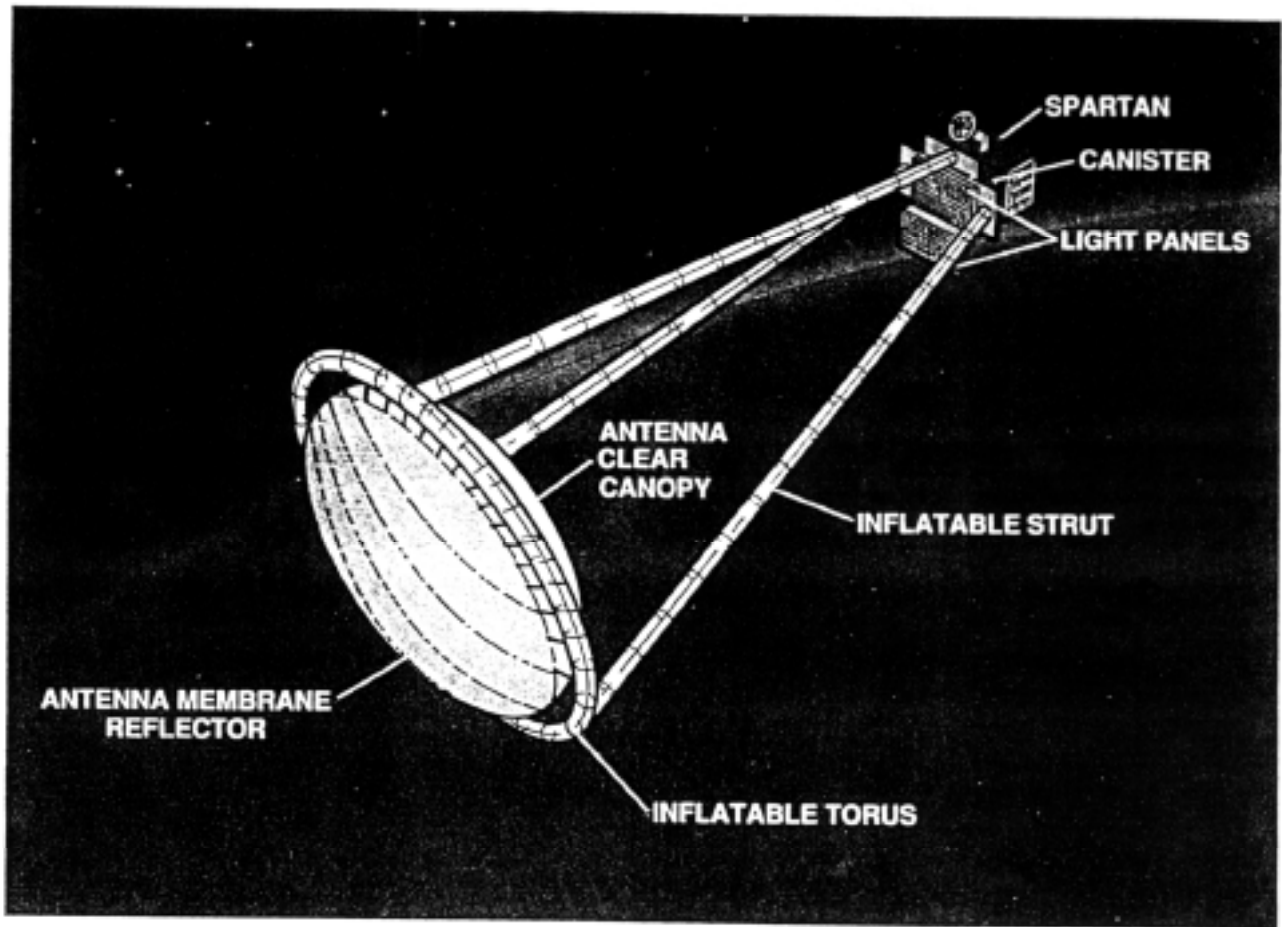
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Fig. 2. Experiment Orbital Configuration

operating stress levels, and materials properties of the membrane and bonded seams to define the number of gores, their zero stress shape, and the operating gas pressure.[4] The membrane-materials properties (which include thickness and non-linear modulus) are experimentally characterized for use in the detail design. The techniques for handling, laying out, marking, cutting, and the butt-joint bonding of the one-quarter-mil mylar membrane were developed on previous programs at L'Garde, Inc., and' demonstrated on a g-meter-diameter reflector structure. Mylar was selected for this experiment because of its availability, low cost, and its extensive use in previous flight applications of inflatable structures.

Fabrication of the 14-meter-diameter reflector was based on using 62 individual one-quarter-mil aluminized mylar gores (Figure 3). The gores were assembled on full-scale, specialized tooling that was designed to account for the difference in curvature etween the zero strain-assembly condition of the membrane and the orbitally loaded configuration. The seams are butt-joined, utilizing a doubler of the same

material on one side only. The adhesive was a standard, space-qualified, flexible material used on a number of previous programs. The ground handling of the membrane required the development of special folding techniques so that the material could be stowed in a small compact package for ease of handling and deployment.

The surface precision of the as-manufactured reflector structure is determined by mounting the membrane on a fixture that simulates its interface with the canopy structure and torus. A pressure differential across the structure (equivalent to that on orbit) produces a surface that represents the "upper bound" of reflector precision that would be achieved if the assembly were perfect. The flight-reflector structure has a measured surface precision on the order of 1 to 2 mm rms.

Canopy

The primary design requirement for the canopy is that it should be a "mirror" image of the reflector structure. That is, the design should be based on using

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Table 1. Inflatable Structure Subsystem Requirements

- Based on L'Garde, Inc., inflatable-deployable antenna concept

- 14-meter off-axis parabolic reflector

- Surface accuracy goal of 1 mm rms

- Optically reflective surface on reflector

- Clear canopy

- Torus and struts provide basic support structure

- Packagable in a container compatible with carrier vehicle

- f/D = 1/2 (Parent)

- Deployment time compatible with single-orbit experiment

- Structural Stability
    Maximum reflector deflection with respect to the spacecraft = 0.50 cm

- Dimensional Stability
    Torus ±0.70 cm on diameter
    Strut ±2.5 cm on length

the same materials and number of gores, but would not require the same surface precision or vapor-deposited aluminum as that used on the mylar. This approach will result in a force balance between the two doubly curved surfaces at their interface where they are assembled to form a len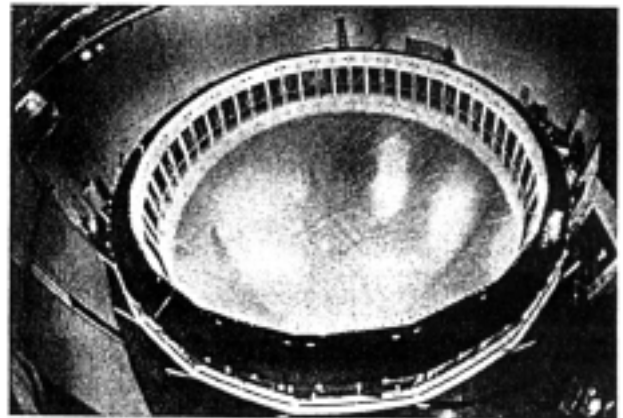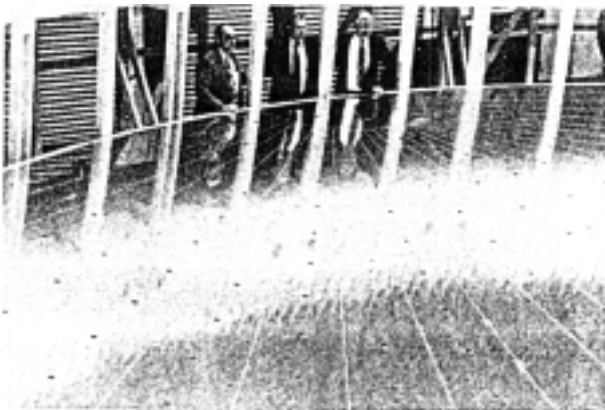ticular structure. Since this canopy structure is made and assembled with the same tooling as that used for the reflector, no special tests were done to verify the canopy's configuration. Assembly of the canopy with the reflector is accomplished by bonding both structures at their outer perimeter to a flexible ring structure. This interface structure provides sufficient stiffness to transfer the loads from the inflated lenticular structure to the torus, yet it is flexible enough to be stowed with the membrane structure. Mechanical packaging tests of this structure are accomplished after assembly of the "lenticular" structure.

Torus

The design of the torus structure is driven by the size of the reflector and the circumferential tension loads from the lenticular structure. These loads produce compression and bending in the torus structure. The material selected was neoprene-coated kevlar because (a) L'Garde, Inc., has extensive experience with the handling and bonding of this material, (b) it is commercially available and inexpensive, (c) it stows efficiently, and (d) it has adequate strength and stiffness for accommodating the experiment. The detail design of the torus is based on a L'Garde, Inc., specialized code, which uses as input the external loading on the torus, its geometry, operating stress level, and the material properties to determine the required diameter and operating pressure.[5] The material properties for the analysis are experimentally characterized. A full-scale engineering model torus is shown in Figure 4.

The specialized tests for the torus include mechanical packaging efficiency and neutral buoyancy flotation to determine the attachment plane for the torus/lenticular reflector assembly under zero g loading conditions. The mechanical packaging consists of repeated stowing of the torus in the canister structure,

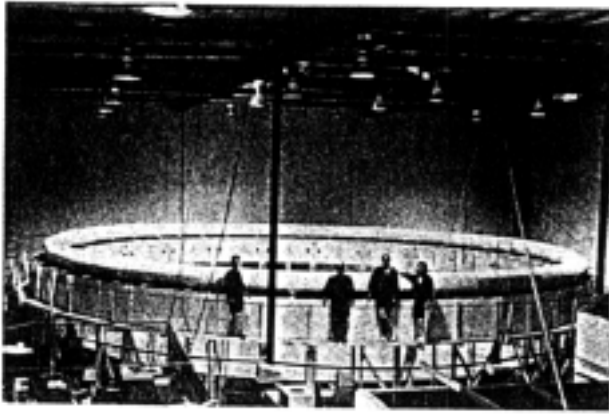Fig. 3. Reflector Membrane - 14.0 meters Diameter

Fig. 4. Torus Structure - 15.2 meters Diameter

using different "folding" techniques. Success for this test is determined by the best packaging efficiency, coupled to a final folding configuration that lends itself to "deployment by inflation", as established by previous flight-hardware experience. The neutral buoyancy state for the torus is achieved by (a) completely filling the structure with water, (b) locating it in a trough filled with water, (c) pressurizing the torus to a differential pressure of 0.02 MPa, which simulates orbital loading, and (d) applying a small amount of distributed flotation to offset the negative buoyant forces resulting from the fluid displaced by the volume of the fabric used for the structure. This technique worked so well that the torus could be manually displaced in the trough with essentially no measurable restoring forces observed. In this unloaded state, the mounting plane for the lenticular structure was located with a rotating laser beam and marked for subsequent attachment of the interface hardware.

Assembly of the torus/lenticular structure is based on using 62 discrete mechanisms located along the mounting plane that can be adjusted individually to impart a uniformly distributed load to the torus. The adjustments are interactively made to simulate the circumferential geometry of the lenticular structure when properly aligned on its mounting fixturing. After the integration of the two structures, additional mechanical packaging tests are done, starting with the folding configurations successfully developed with the torus structure.

Struts

The design drivers for the struts include (a) a required length of 28 meters, (b) a minimum structural frequency of 0.25 Hz, (c) manufacturing tolerances of 0.5 cm for bending and torsion distortions, and (d) an

operating pressure the same as that for the torus. The detail design is based on using the same neoprene-coated kevlar material as used on the torus. The diameter and resulting bending stiffness are based on a requirement for a minimum natural frequency to accommodate the orbital stability needed for the experiment. The minimum diameter required was 35.6 cm. The materials-processing and fabrication techniques used are near identical to the ones used on the torus. A full-scale engineering model is shown in Figure 5.

Specialized testing included manufacturing evaluation for bending, twist, and mechanical packaging efficiency. The quality of the manufactured struts was established by "floating" them in a full-length water trough. Calibration marks on the ends of the tubes indicated the degree of relative rotation. Measurement of lateral translation along the length of the strut, as it is rotated in the water trough, is a direct measure of the bending as a result of manufacturing. These tests showed that the torsional permanent set in the structure was about 15°, but did not affect the functional performance, and the bending was on the order of 50 mm maximum deflection.

The end fittings for the struts are essentially flat plates machined from aluminum and bonded to the interior area of the end of the tubes. Such fittings are simple, inexpensive, and easy to interface with the canister panel-support fittings and the torus-to-strut interface fittings. The geometry of these fittings, because of their size and rigidity, has a significant impact on the mechanical packaging techniques. Folding patterns were developed that kept the thin membrane material from the vicinity of the end fittings.

The results of the mechanical packaging tests of the canopy, torus, and struts individually were used for
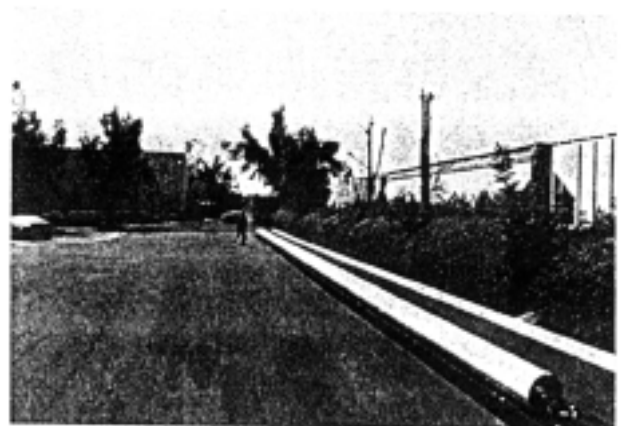

Fig. 5. Structure - 30.5 meters Long

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arriving at the packaging techniques for the complete till-size inflatable structure. Validation of this approach for stowing the inflatable structure was done by adding MLI blankets and electrical wiring to the inflatable model and successfully packaging it in the canister.

Canister

The design drivers for the canister include (a) providing the load-carrying structure for all elements of the experiment, except the equipment panel that remains with the Spartan, (b) interface structure with the Spartan, (c) deployable panels to accommodate ejection of the stowed inflatable antenna structure, (d) smooth surface compartment to house the stowed inflatable structure, (e) interface with the struts, and (f) high structural-design margins to minimize the need for expensive structural-qualification verification testing (Table 2).

The design approach for the canister (or bus structure) employs aluminum honeycomb panels for the basic load-carrying elements of this structure. The justification for this selection is that (a) it is very stiff for its weight, (b) it is available and relatively inexpensive, (c) the smooth face sheets provide the appropriate surfaces for the stowed inflatable structure, and (d) L'Garde, Inc., has extensive experience using this type of structure.

The configuration development of the canister starts with (a) the volume required for the stowed inflatable antenna structure, (b) the volume and mounting surfaces required for the inflation system, electronics,

Table 2. Canister Subsystem Requirements

* House and support all elements of experiment

* Basic load-carrying structure

* Structural design loads from Spartan

* Deployable

* Provide ejector for inflatable structure

* Provide interface for struts

* Interface with Spartan

* High design margins

and functional elements of the SAMS, (c) the geometry of the interface with the Spartan and the limitations imposed by the dynamic envelope of the STS, (d) mechanization to accommodate release of the stowed inflatable structure in a controlled manner, (e) providing the mounting points for the three strut structures, and (f) taking advantage of the weight available for the experiment to develop large, structural design margins and a structure with a first natural mode above 35 Hz to preclude a requirement for a modal survey test.

These requirements resulted in a canister structure that is 2.0 meters long, 1.1 meters wide, and 0.46 meters high. Four spring-loaded doors open to allow deployment of the inflatable antenna structure. Part of the SAMS light panel is attached to the inside surface of the top cover, and the three side doors contain "pods" for storage of the inflatable struts. All doors are held in place by pin-puller latches. A large spring-loaded plate is located in the floor of the canister for purposes of ejecting the inflatable structure at the beginning of the deployment sequence. This plate also supports the rest of the light panels.

The structural design of the canister was based on quasi-static acceleration loads defined at the Spartan center of mass. A standard finite-element code for the determination of panel stresses and loads was used with hand analyses for fittings and mechanisms stress, and margins. Because of (a) the complexity of the honeycomb construction for modeling, (b) the geometry of the canister, (c) the mechanisms tie points needed to accommodate articulation of the panels, (d) and an ejection plate for pushing the stowed inflatable structure away from the canister, the final model was 23,000 d.o.f. This model, after experimental verification of the fundamental structural modes below 50 Hz, was used with the Spartan analytical model for the coupled-loads analysis for the combined loads of the Spartan/IAE on the shuttle.

Special functional tests for the canister included (a) panel deployment, (b) ejection-panel spring calibration, (c) pyro/pin-puller release, and (d) structural natural frequency identification. The full-scale engineering model and hardware used for the tests are shown in Figure 6. The panel tests consisted of repeated articulations with adjustments of spring stiffness and damping of the actuator to ensure timely and low shock deployment. The ejection-panel tests were based on repeated deployments of a mass simulation of the inflatable structure to accommodate evaluation and
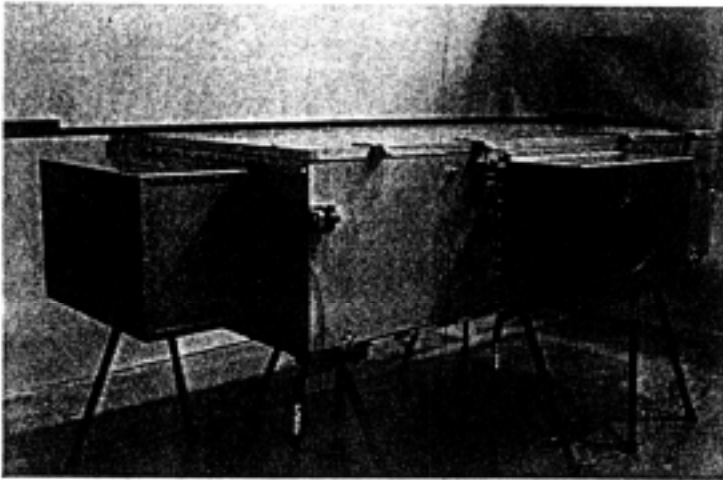
Fig. 6. Canister Structure (Bus)

adjustment of the spring cluster to achieve the proper ejection velocity. Pyro pin-puller release tests were done to demonstrate a "clean" release and functional performance of the "initial motion" kick-off springs. Forced vibration tests of the full-scale engineering test unit, which simulate the full-up canister system, were conducted at the Goddard Space Flight Center (GSFC) to determine all the significant structural modes below ⁻0 Hz which turned out to be 35 Hz.. The results were .en used for test/analysis correlation for validation of the structural model that was used for the Spartan/IAE/STS-coupled loads analysis. A highly non-linear dynamic response of the stowed inflatable structure resulted in the need to analytically account for the change in the response frequency of two significant modes in the linear analytical model. This was necessary to account for the actual frequency shift of several Hz in the structure when under high-level dynamic loading, since simulation of the non-linear characteristics is not practical.

Surface Accuracy Measurement System

The design drivers for the surface measurement subsystem include (a) remote measurement of the reflector surface on orbit and in the presence of near direct sunlight with a resolution of ± 0.1 mm rms, (b) coverage of at least 90% of the surface, (c) a measurement cycle of no more than 40 seconds, and (d) a development and flight hardware cost of under $1M (Table 3). A number of systems were identified for possible application to IAE. However, only one system as even close to being affordable for the IAE. That system is based on a Digital Imaging Radiometer (DIR) developed by McDonnell Douglas for measurement of

slope errors on ground-based solar concentrators.[6,7,8] The concept is based on using a number of discrete light sources, located near the center of curvature of a surface, and then photographing the reflected rays. Surface deviations from a perfect surface will result in shading patterns as seen by the camera. The magnitude and distribution of such shading patterns are used to determine the slope error distribution of the antenna aperture. The components needed to implement this approach include (a) a number of discrete light sources mounted on panels, (b) high resolution video cameras, (c) video records, and (d) electronic circuits to sequence and control the triggering of a large number of short-interval light bursts.

The initial step of the design was to analytically characterize the system performance parametrically, with
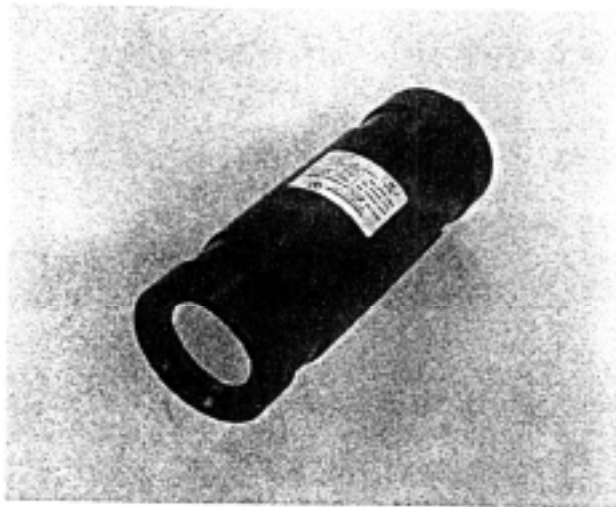
Table 3. SAMS Subsystem Requirements

• Remote measurement of reflector surface
• Concept based on MDAC DIR
• Measurement data recorded on VCR
• Sample data transmitted to STS
• Measurement accuracy ± 0.1 mm rms
• Surface Coverage ≥ 90 percent
• Surface measurement cycle ≤ 40 seconds
• Development and flight hardware under $1M

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the resulting information used to determine (a) the number of light sources? (b) the light panel size and shape, (c) the characteristics of the light sources, such as wavelength and luminous intensity, (d) the camera characteristics that include pixel resolution, flux sensitivity, band pass filter and its center, and (e) the electrical and software requirements for operating the cameras and timing for the light panels.
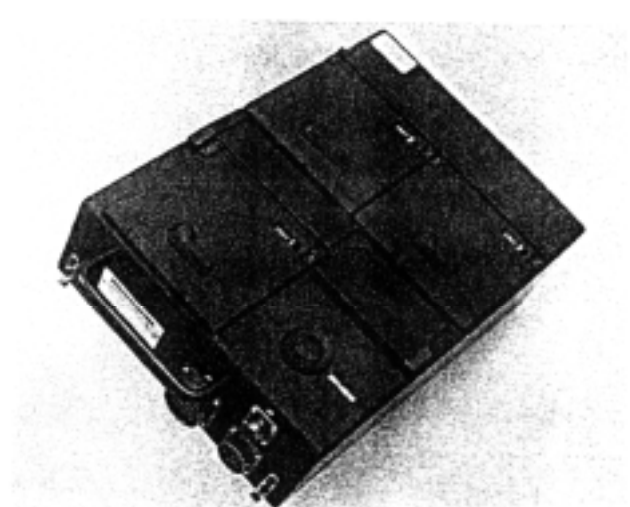
The next phase of system development involved identification of flight-qualified components for the system. The biggest challenge, of course, was the video cameras. Fortunately, a Videospection CCD camera that had been previously flown on the STS was identified and found to meet the functional performance requirements (Figure 7). The next challenge was to identify light sources (such as high-output LEDs) that were available in large numbers at low cost, since the final design utilizes 512 clusters of 36 LEDs (Figure 7). A relatively new product by Rohm Corp. was located, but was not flight-qualified. However, since the flight system will operate with up to 20% LED failure, the usual flight certification was not required. The mounting of the individual LEDs on the supporting panels utilized standard techniques for mounting electronic components on printed wiring boards.
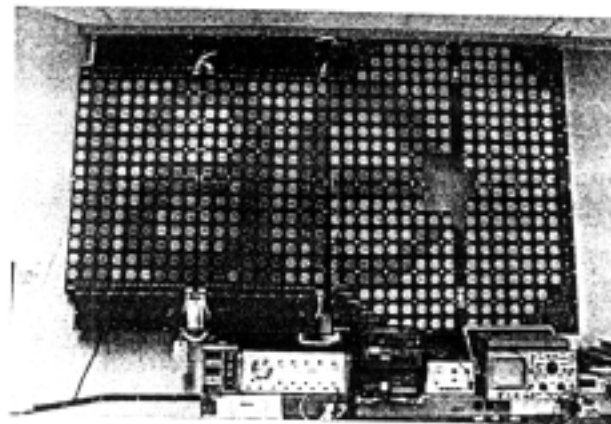
The special tests required for development of the flight hardware included (a) reflectivity of the aluminized mylar to LED illumination, (b) camera aperture evaluation and calibration, (c) light-source intensity evaluation, (d) system characterization, using a scale-size calibration mirror, and (e) full-scale calibration, using a 3-meter-inflatable section of the full-size reflector structure. The reflectivity of the illuminized mylar was obtained by mounting the actual aluminized mylar membrane on flat plates, illuminating the reflection surface with the flight-type LEDs, and measuring the return signal. This reflectivity data was used in the design of a 0.30 meter-diameter glass mirror to be used

VIDEO CAMERA

VCR

LIGHT PANEL SET

Fig. 7. Surface Accuracy Measurement System

for subsequent system calibration. The camera-aperture calibration was accomplished by tests in direct sunlight and in the dark with variable LED intensity. The light-source intensity was determined by direct measurement as a function of applied voltage. The complete system was evaluated for the first time by using the 0.30 meter-diameter mirror, which had the same reflectivity as that of the membrane and a 28-meter radius of curvature. This test established the required flux density of the return signal, the required camera-aperture opening, and the adequacy of the LED's output. The full-scale test, using a 3-meter section of the 14-meter reflector offered the first opportunity to evaluate the system in a realistic manner. By rotating the camera so that its field or view moves across the surface of the inflatable reflector, a simulation of an on-orbit measurement has been achieved. The results of this test demonstrated that (a) the measurement resolution of the system was on the order of 0.1 to 0.2 mm rms, (b) the final camera-aperture settings were established, (c) the time required for multiple measurements was verified, and (d) the final configuration for the light-panel performance was determined.

The demonstrated performance of the surface-measurement system effectively satisfied the subsystem design requirements. In fact, a number of performance results exceeded expectation. The total development and hardware cost was under $1M; measurements were successfully made in near direct sunlight; and the flight-qualified cameras were more than adequate for the system.

Inflation Subsystem

The key design drivers for the inflation subsystem included (a) high-pressure nitrogen gas storage for the inflatable structure, (b) sensors, valves, and regulators for implementing the control of inflation, (c) using a functional concept based on previous successful L'Garde, Inc., designs, and (d) maximizing the use of Spartan cold-gas attitude control-system components (Table 4).

The functional design of the subsystem is nearly identical in concept to the ones successfully flown by L'Garde, Inc., for much smaller inflatable structures. Analysis of mass flow was used to establish component requirements. Component selection was based on previously qualified hardware used for the Spartan attitude-control, cold-gas system and on previous L'Garde, Inc., flight systems. The supporting structure

Table 4. Inflation Subsystem Requirements

Active pressure control system
Provide pressure vessels, regulators, sensors, and valves to supply 52930 cc N_2 at 20.68 MPa
Control inflation pressure to the required level
- Deployment, design flow rate $\pm 3\%$ - Deployed, support structure 0.02 MPa $\pm 3\%$ static   - Deployed lenticular structure 2.07×10^{-4} MPa $\pm 3\%$
Maximize use of Spartan components
Maximize use of previous successful L'Garde, Inc., designs

used for mounting the tanks, plumbing, and components is an aluminum honeycomb panel similar to that used for the canister. This panel also contains the electronics, control boxes, and SAMS video cameras and is permanently attached to the Spartan for return to earth after completion of the experiment. The two large structural composite gas tanks utilize the same mounting configuration as that for Spartan to minimize requalification costs. The component mounting and tubing are similar to previously used designs by L'Garde, Inc. (Figure 8). Design factors of 2.5 over operating pressure were used. No attempt was made to develop a light-weight, highly compact inflation system for this experiment because of cost limitations.

Specialized testing included leak, proof-pressure, and functional performance validation. Simulation of
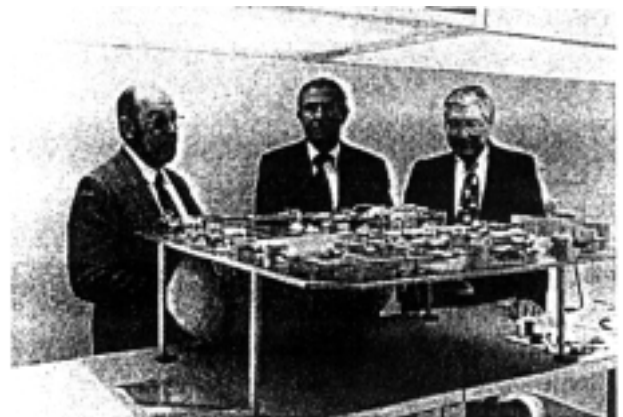

Fig. 8. Inflation System

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orbital inflation was done by using two large tanks which were evacuated and then filled with gas using the sensing and gas-flow control techniques proposed for the experiment. Refinements of the design were based on these test results.

The inflation subsystem development was relatively straightforward, and its functional performance easily satisfied the subsystem requirements.
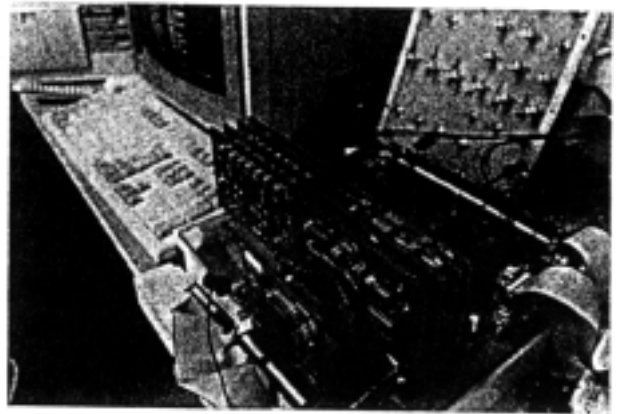
Electronic Subsystem

The design driver for the electronic subsystem is the initiation, sequencing, and control of all IAE functions that include (a) pyrotechnic release devices, (b) pyrotechnic valves, (c) synchronization/control of the video cameras, VCRs, and light panels, (d) multiplexing of engineering data, (e) logic and control of the inflatable pressures, and (f) interface with the Spartan (Table 5). The electronics are designed around the Intel 87C196K-MOS processor.

The subsystem design was based on conventional electrical-circuit analysis and hardware packaging techniques successfully used on previous L'Garde, Inc., flight hardware. The electrical components were selected from JPL parts lists that identify sources for high-quality and reliable hardware. The components are mounted on four-layer circuit boards using standard approaches. The circuit boards are integrated by insertion into the motherboard (Figure 9). The completed motherboard/circuit board assembly is housed in an aluminum enclosure which is mounted on the equipment assembly structure. Cabling used in the electronic subsystem utilizes standard nickel-plated-type connectors.

Functional tests were based on component evaluation, circuit characterization, assembly performance, and overall subsystem capability.

Table 5. Electronic Subsystem Requirements

₁Experiment sequence and timing
₁Deployment control and inflation control
₁Instrumentation control
₁SAMS control
₁Health and status monitoring
⚹ MIL components to maximum extent possible

PROTOTYPE ELECTRONICS

Fig. 9. Electronic Subsystem

Environmental Interactions

The experiment structure/environmental interactions include the effects of (a) atmospheric drag on the stability of the structure, (b) orbital thermal environment and atomic oxygen on the thin-film materials, (c) UV radiation on the thin-film materials, (d) low-orbit radiation on electronic components and, (e) impact of space debris on the structure.

The atmospheric drag on the 14-meter solid-surface antenna reflector results in a significant relative separation of the Spartan/IAE from the Orbiter. This separation (without STS station keeping) is 8 km, 20-km, and 50 km on the first, second, and third orbit, respectively. Consequently, the experiment was designed to be completed during just one orbit to minimize STS propellant. Additionally, analysis has shown that these same drag forces tend to stabilize the deployed structure with its longitudinal axis parallel to the ram direction. This means that minimal control authority is required.

Consideration of the orbital thermal environment is included in the design of the inflatable support structure by the addition of MLI blankets to the torus and struts to maintain dimensional stability. However, the lenticular structure, which consists of the transparent canopy and the aluminized mylar reflector, was not treated in any way for the control of temperature during the one-orbit experiment. Consequently, the internal pressure will decrease significantly when the structure falls in the earth's shadow; but the inflation system will compensate for this. However, for a long-term application of this concept, different and improved flexible materials and thermal control coatings will be

employed to maintain dimensional stability of the reflector.

Atomic oxygen is not considered a problem for this experiment because of its one-orbit duration. The estimated degradation of the reflector membrane for one orbit is 7.62×10^{-5} mm. However, for real applications, special materials and/or surface coating will have to be utilized.

The effects of UV radiation on the thin-film materials and the South Atlantic Anomaly on the IAE electronics were addressed. There are a number of candidate membrane materials with real potential for being radiation resistant, as compared to those used for the experiments. For long-term applications, such materials would have to be used. Cost constraints for the experiment precluded the use radiation-hardened electronic components. Therefore, to significantly lower the probability of a single-event upset in the 296 km and $39°$ inclination orbit, STS operations specify that the Spartan/IAE will not be put into orbit near the South Atlantic Anomaly.

The impact of the IAE colliding with sizeable space debris is not considered a problem for the experiment because of adequate make-up gas. Even in a long-term application, this is still not a major problem, since the torus and struts would be rigidized, and the operating pressure in the lenticular structure would be two orders of magnitude below that of the IAE, requiring only a small amount of make-up gas.

Conclusions

Significant accomplishments at this time include (a) the fabrication of a large, flight-quality-deployable space structure for under $1M, (b) demonstration of mechanical packaging of a 14- by 28-meter space structure in a container the size of a large office desk, (c) manufacture of a 14-meter-diameter reflector membrane that has a surface precision on the order of 1 to 2 mm rms, (d) development of a space-qualified, surface-accuracy measurement system that operates in the presence of near direct sunlight for well under $1M, and (e) the experimental determination of the torus/canopy interface on a large, inflatable torus by simulating O-g in a full-scale, neutral-buoyancy trough.

The remaining experiment objectives to be accomplished on orbit include (a) validation and characterization of the deployment sequence, (b) determination of the reflector-surface precision and its thermal stability in a realistic operational environment.

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