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Inflatable Antenna Technology wiht Preliminary Shuttle Experiment Results and Potential Applications

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INFLATABLE ANTENNA TECHNOLOGY WITH PRELIMINARY SHUTTLE EXPERIMENT RESULTS AND POTENTIAL APPLICATIONS

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ABSTRACT

This paper describes the status of NASA's Inflatable Antenna Experiment (IAE) and a brief discussion on potential future applications. The space experiment of a 14-meter diameter reflector antenna was flown and deployed successfully aboard the Space Shuttle, STS-77, launched May 19, 1996. Since the flight data is still being processed and reduced, only preliminary results can be presented at this time. The development of the IAE will be discussed along with the results of ground test measurements which were conducted to determine the overall mechanical and projected electrical performance characteristics of this inflatable concept. Large, space-deployable antennas are needed for numerous applications which include mobile communications, Earth remote sensing, and space-based radar systems. Due to the traditionally high cost to develop and launch such large antennas, new technology must be developed which is cheaper, faster, and better. Inflatable antenna technology provides the opportunity to accomplish these objectives.

Keywords: Deployable Antennas, Antenna Measurements, Space Experiment.

1.0 INTRODUCTION

A relatively new and unique concept for an inflatable-deployable space antenna structure that has tremendous potential for accommodating such stringent user requirements is under development by L'Garde, Inc., Tustin, California [1,2,3]. The inflatable antenna concept is based on technology developed by L'Garde, Inc., during the past 25 years, which includes the design, manufacture, and ground and flight testing of inflatable space structures [4]. 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 [5]. 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 Inflatable Antenna Experiment (IAE) was flown on the Space Shuttle, STS-77 and this paper describes the design of the experiment flight hardware and identifies key areas for each of the subsystems that comprise the experiment system. The IAE configuration is presented in Figure 1. Preliminary results of the flight experiment are presented along with the results of ground measurements of surface accuracy, radiation pattern calculations for the 14-meter reflector; and potential applications are discussed for a future microwave radiometer system for soil moisture measurements from low Earth orbit.

2.0 EXPERIMENT-SYSTEM PERFORMANCE OBJECTIVES AND REQUIREMENTS

The experiment system performance objectives are: (a) develop large, low cost antenna structure, (b) validate mechanical packaging efficiency, (c) demonstrate deployment reliability on orbit, and (d) measure surface precision on orbit. The experiment-system functional equirements are based on these experiment objectives and the inflatable structures concept capability, constrained by the NASA experiment resources available and the capability of the experiment carrier, the Spartan. 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 commercial mobile communications, and Earth remote sensing applications. 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 was done on orbit, which provided a realistic operational environment. High mechanical-packaging efficiency was 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.

3.0 SUBSYSTEM FUNCTIONAL REQUIREMENTS

The experiment-subsystem functional requirements are driven by the system functional requirements, with design parameters bounded by the L'Garde, Inc., flight data base for inflatable structures and the environmental-interaction effects on the experiment hardware. 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. The combinations 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 are satisfied.

3.1 Inflatable Structure

The antenna inflatable 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.

3.2 Canister Bus Structure

The design drivers for the canister bus structure 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.

3.3 Surface Accuracy Measurement System

The design drivers for the surface accuracy measurement subsystem (SAMS) 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 $lM. A number of systems were identified for possible application to the experiment, but only one was found to be affordable. That system is based on a Digital Imaging Radiometer developed by McDonnell Douglas for measurment of slope errors on ground-based solar concentrators [3,4].

3.4 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.

3.5 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 spacecraft.

4.0 ORBITAL SYSTEM

4.1 Orbital Scenario

The orbital functional scenario for the experiment started with the Spartan being placed overboard by the STS Remote Manipulator System (RMS)as shown in Figure 2. Once the orbiter has moved a safe distance away and the Spartan has been stabilized by its attitude control system, a start command from the Spartan to the experiment controller initiates implementation of the experiment. Antenna deployment commences withthe opening of the canister doors; the spring-loaded floor plate then pushes the stowed structure away from the canister. The inflation system then provides nitrogen gas to the stowed inflatable structure. The entire deployment sequence will take on the order of 5 minutes. Measurements of surface precision for several sun angles and reflector/canopy inflation pressures will be made during the first one or two orbits. Since the high drag of the reflector structure will cause separation of the Spartan from the orbiter, and only one orbit is required to implement the experiment, the antenna will be separated from the Spartan at the completion of the measurements. The Spartan with the experiment data will be recovered by the orbiter at the end of its standard mission.

4.2 Orbital Deployment Sequence

To be meaningful, the validation of deployment needs to address all of the events, which include (a) initial position and configuration of the stowed reflector structure after it is released from the canister, (b) the change of structural configuration associated with each of the four deployment sequences, and (c) the time required for inflation of each of the sequences. Deployment starts when the stowed inflatable structure is ejected from the canister by a spring-loaded floor plate. Next the deployment of the struts is initiated by the strain energy resulting from stowing the inflatable members. Deployment is then completed by inflation of the struts. By this time, deployment of the torus has been initiated by release of its strain energy and completed by inflation. After this support structure has been completely deployed the reflector and canopy are then inflated.

5.0 SURFACE ACCURACY MEASUREMENTS - GROUND TEST RESULTS

The ground-based test program addressed the development, evaluation, and verification of mechanisms, inflatable and canister structures, instrumentation systems, electronics subsystems, and the inflation system. A major part of the ground-based test program was to determine the surface accuracy of the 14-meter-diameter inflatable reflector to the fullest extent possible and to validated the operation of the surface measurement system. Due to the size of the 14-meter structure a 0.2 sector of the reflector was developed for calibration of the surface measurement system. The 14-meter reflector surface precision was measured photogrametrically to characterize this class of structure and verify manufacturing capability. The test configuration for the 14-meter-diameter reflector is shown in Figure 3. The surface accuracy measurement results for the 14-meter (IAE) reflector are presented in Figure 4 and surface distortion contours are presented in 2-mm increments. Even with l-g effects, the surface accuracy was found to be less than l-mm over a large portion (8-10 meters) over the entire surface. The surface accuracy was determined using photogrammetric techniques and the x, y, and z target measurements were used in characterizing the surface for radiation pattern calculations. Radiation patterns were calculated for a frequency of 1.4 Ghz since that is the frequency proposed for the Earth remote sensing application. The results of these radiation pattern calculations are presented in Figure 5.

6.0 INFLATABLE ANTENNA EXPERIMENT RESULTS - PRELIMINARY

Preliminary flight data results indicate that (a) the Spartan performed flawlessly, (b) the canister doors articulated nominally, (c) deployment sequence of inflatable structure was significantly affected by an unexpected amount of residual air in the stowed structure and release of strain energy in the torus structure, (d) inflatable support structure achieved its nominal pressure of 3 psi, (e) complete deployment of the lenticular structure does not appear to have been achieved, (f) the SAMS operated correctly and positioned the rim of the lenticular structure but was unable to characterize the reflector structure, and (g) outstanding photographic and video coverage from the orbiter.

7.0 POTENTIAL FUTURE APPLICATIONS OF INFLATABLE ANTENNA TECHNOLOGY

Current operational technology is unable to fulfill key science needs in Earth remote sensing from space [7]. For example, microwave measurements of sea ice, soil moisture, salinity, and wind speed (over oceans) are not being obtained at the required spatial resolution. Recent studies [8] have identified soil moisture measurements at 10 to 25 km resolution as the general science driver. Research at Langley Research Center has investigated critical technologies for developing advanced microwave radiometers and the results indicate that novel, inflatable reflector concepts (such as the IAE) hold much promise for high spatial resolution, small launch vehicle systems. Therefore, an inflatable antenna system could enable Earth science observations, especially for the 20 to 30 meter category of space systems necessary for soil moisture measurements. For example, an inflatable radiometer imaging system is currently being proposed by JPL for soil moisture and ocean salinity [8].

8.0 SUMMARY AND CONCLUSIONS

The overall experiment was a tremendous success. New, unique and low cost technology was demonstrated on orbit. For example, (a) a very large inflatable antenna structure was built for about $lM, (b) efficient packaging was demonstrated by stowing a 50-ft inflatable structure in a container the size of an office desk, (c) a 14-meter diameter reflector structure was manufactured having a surface precision on the order of a few millimeters, (d) the robustness of a new and unique reflector structure was verified by successful orbital deployment and (e) results of this experiment will focus the direction of technology development for a new class of space deployable structure.

ACKNOWLEDGEMENTS

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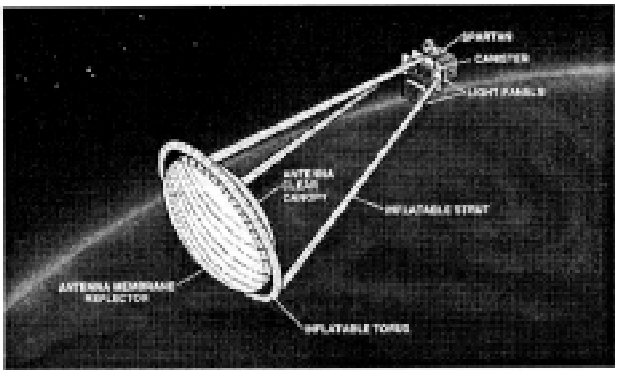

Figure 1. - Inflatable antenna experiment configuration

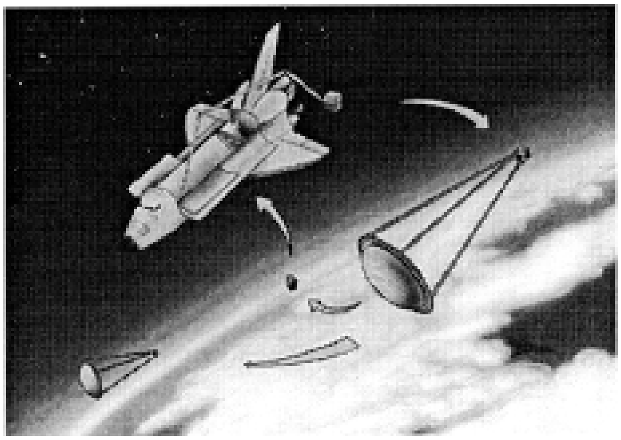

Figure 2. - Orbital deployment sequence of the inflatable antenna experiment

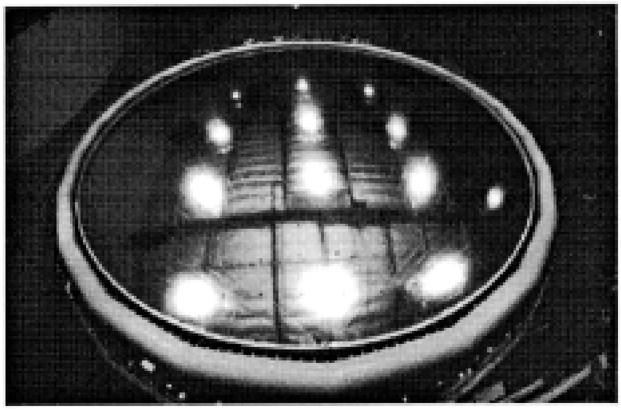

Figure 3. - Ground Test Configuration of the 14-meter diameter inflated reflector for surface accuracy measurement

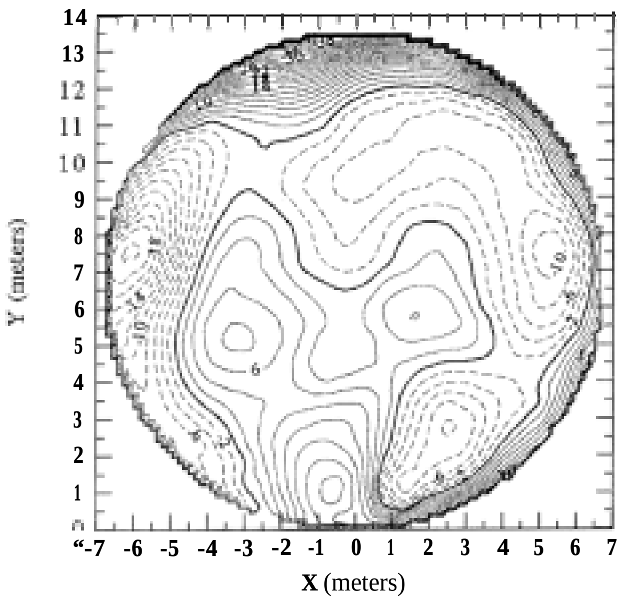

Figure 4. - Measured surface distortions for the 14-meter inflatable reflector during ground testing

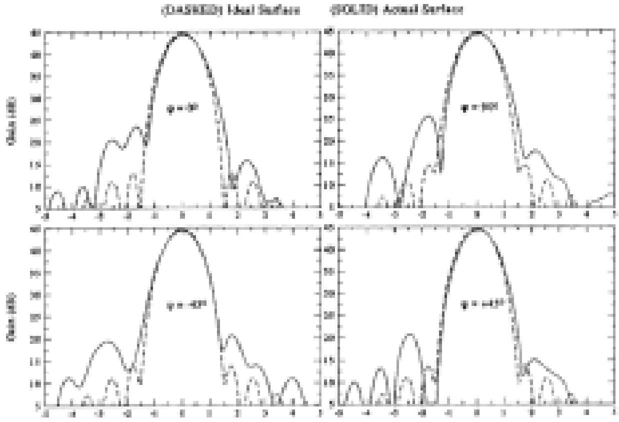

Figure 5. - Calculated radiation patterns of the 14-meter inflatable reflector during ground testing

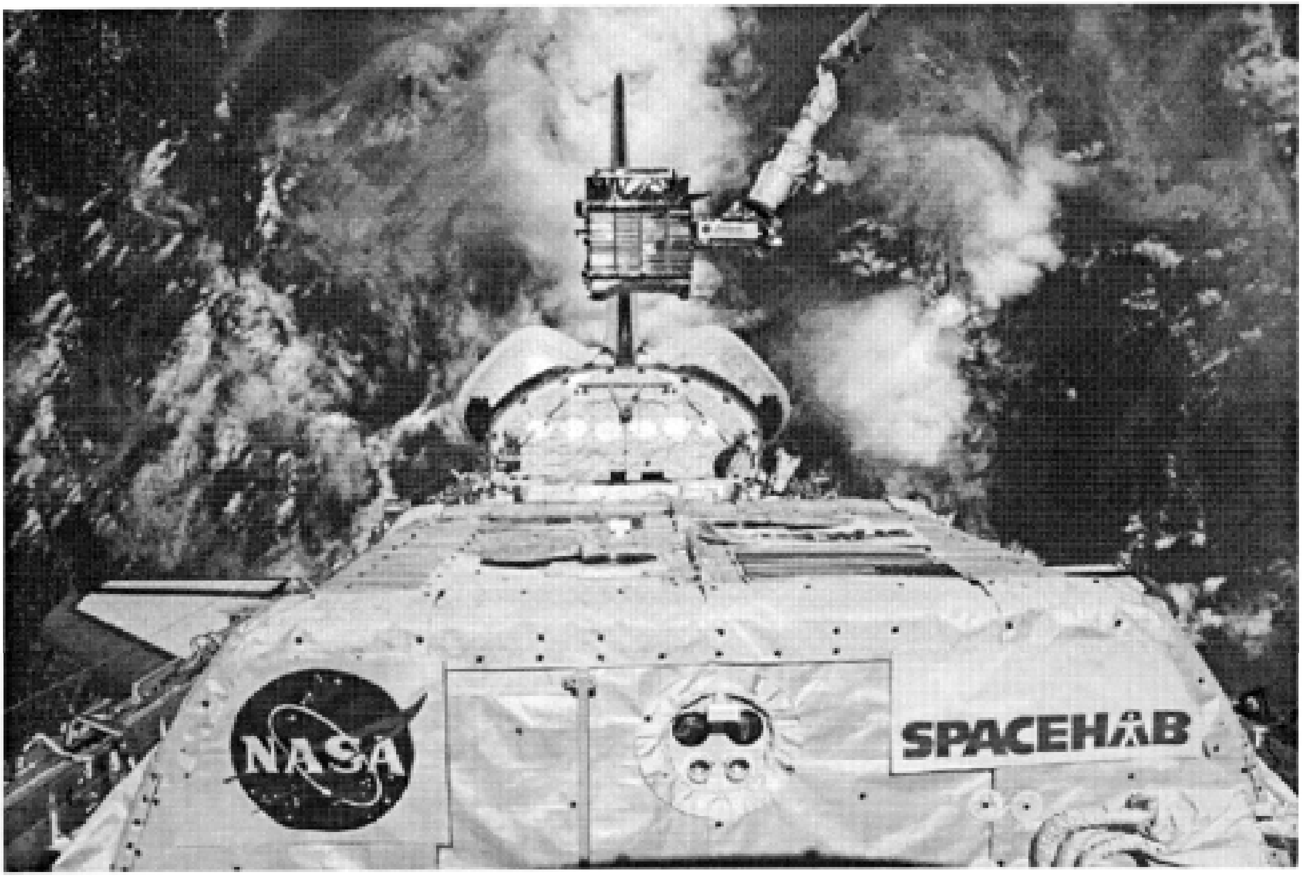

Figure 6. - Photograph of the IAE/Spartan being removed from Endeavor by the Remote Manipulator System

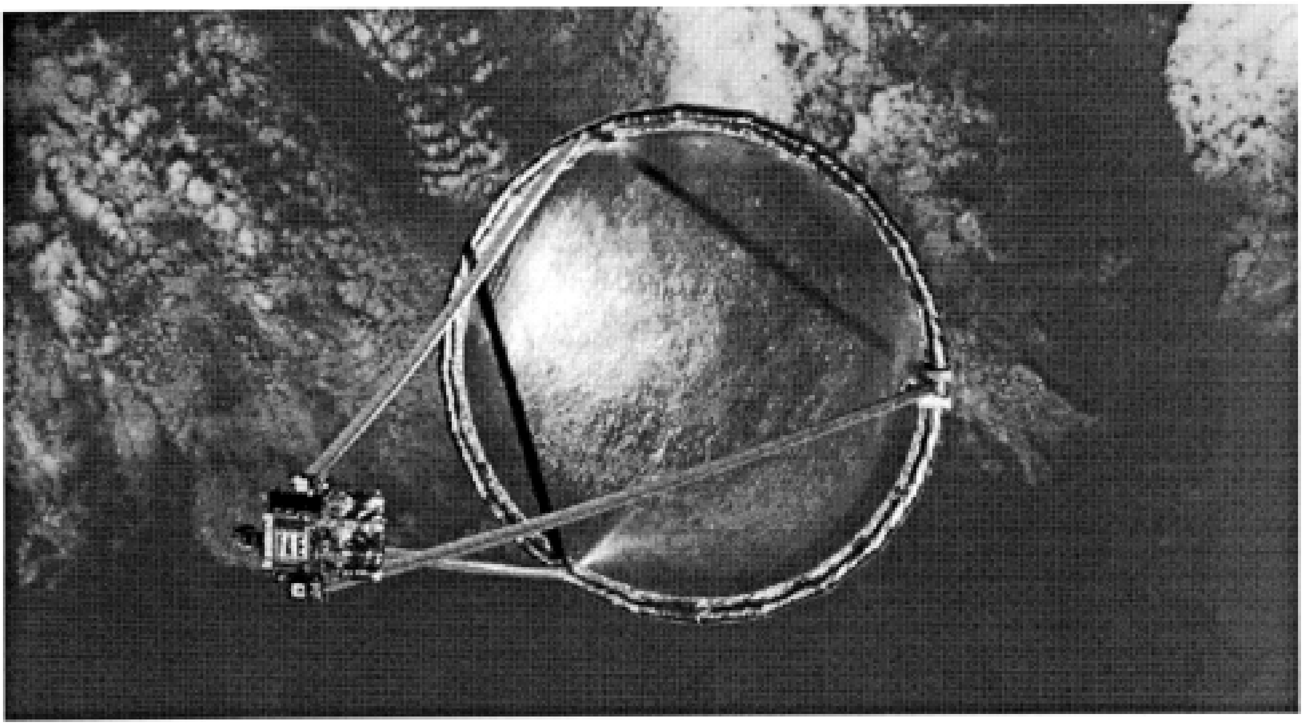

Figure 7. - Photograph of the IAE in orbit as seen by Endeavor, positioned toward the sun

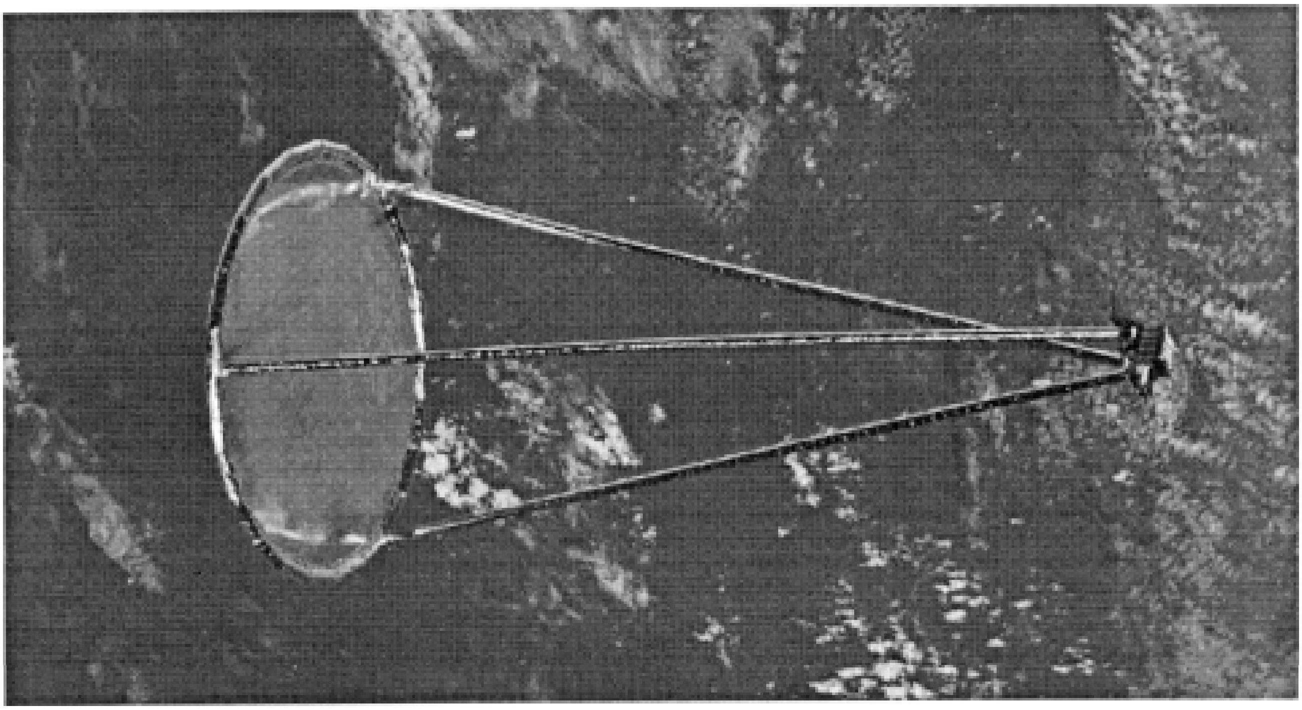

Figure 8. - Photograph of the IAE in orbit as seen by Endeavor, side view

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