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SIGNIFICANCE OF THE INFLATABLE ANTENNA EXPERIMENT TECHNOLOGY

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ABSTRACT

The IN-STEP Inflatable Antenna Experiment was intended to demonstrate high payoff technology for large, inflatable space antenna structures, in a realistic operational environment. The experiment was based on the L'Garde, Inc. concept for a large, offset, parabolic reflector antenna and their associated technology data base at the time of initiation of the experiment in the early 1990's. The level of technology maturity at L'Garde, Inc. for their new antenna concept was commensurate with extensive space flight experiment with small space deployable decoy [redacted] type structures and the capability for producing large flight prototype structural components such as reflector structures, strut and torus structures and lenticular structures. Since the IAE was the first large, high precision, multiple structural elements, inflatable deployable space structure on orbit, a number of totally new technologies were demonstrated and evaluated. The new and unique technologies include mechanical packaging techniques for membrane reflectors and rigidizable a type support structures; handling, processing and assembly of thin membrane materials; ascent venting techniques of or lenticular and strut/torus type structures; deployment control techniques for both reflector and support structures; and the design and manufacturing of large, high precision, doubly curved, thin membrane reflecture structures. Due to the lack of meaningful hardware demonstrations to establish the maturity of these technologies, prior to IAE, there was no serious interest by the Antenna User Community. The successful completion advent of the experiment seems to have [redacted] changed this.

Introduction

The objective of the IAE was to demonstrate a level of technology maturity for large, inflatable deployable, space antenna structures based on the technology data base at L'Garde, Inc. at the time of initiation of the experiment. At the time the experiment hardware was developed, there was a variation of the maturity level of the critical technologies. However, it was felt that the lowest level of technology maturity was still consistent with the experiment basic criteria for high technology payoff, low cost and moderate risk. The specific critical technologies that had not benefited from full scale hardware demonstrations, prior to the experiment included ascent venting, deployment control and TBD. This paper describes the technical approach used for the critical technologies, discusses the adequacy of the technology prior to and/or on orbit and the implementations of experiment results on future technology development.

Conclusions

The conclusions address how well the critical technologies demonstrated on orbit met the objectives of the experiment and the needs of future experiments and applications of this technology.

The deployment control of each major structural element, including the canopy, is required maintain high reliability. The orbital deployment was complete and successful due to the robust nature of inflatable deployable structures. The need for major improvement of

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PACKAGING TECHNIQUES FOR REFLECTOR AND SUPPORT STRUCTURE

The mechanical packaging techniques used for IAE were based on a combination of recent experience with a large number of small inflatable structures and new techniques tailored for the unique geometry of the experiment hardware.

The first major decision on packaging techniques was to separate the three strut structures from the cavity that contained the reflector structure. This approach was used to eliminate physical interaction between the struts and torus structure during deployment, so that separate control techniques could be used for each element of the support structure.

The highest packaging efficiency for the struts results from folding them in a "z" configuration with a separate container for each structure, referred to as "pods". This arrangement allows the struts to be pulled from their pods by the inertial forces of the reflector structure without interaction between them or the torus structure during the deployment.

The folding technique used for the reflector structure, which includes the lenticular structure and the torus, was driven by the folding pattern of the torus structure. In order to interface the ejection plate with the most durable inflatable structure, the torus, three segments of the torus, located between the joints with the struts, were folded into short and wide pedestal type packages and placed parallel to each other on the ejection plate. The center part of the lenticular structure, which was not constrained by the torus at its outer edges, was folded into a "z" pattern and then located on top of the stowed torus structure. This packaging technique resulted in a near rectangular configuration that fit quite well into the rectangular canister structure. For the small cavities in the corners of the canister that were not occupied by the inflatable structure, dunnage, made from "light foam" was used. The total volume occupied by dunnage was TBD_____% of the total canister volume. These packaging techniques were based on the assumption that the amount of residual gas in the stowed would have minimal impact on the planned deployment sequence. Based on the actual orbital performance, the combination of such folding techniques, along with control deployment devices, now under development of L'Garde, Inc., is expected to result in a highly controlled deployment sequence.

HANDLING, PROCESSING AND ASSEMBLY OF MEMBRANE MATERIALS

The reflector structure consisted of 62 aluminized mylar gores that were 7 microns thick. Their geometric shape was based on an analytical process that utilized a special computer codes. The membrane material is stored on rolls that are 3 meters wide. The surfaces of the tables and fixturing which were used to support the delicate membrane material must be very smooth and free of sharp obstacles. The cutting of the gores is done by a computer controlled laser machine ~~that feeds~~ the membrane from ~~their~~ storage rolls onto a table that supports the mobile cutting tool. The gores are folded/transported/assembled by hand. The assembly process consists of placing the edge of two gores precisely against each other while being supported by curved tooling. At that time a tape doubler is placed over the two adjoining gore edges and bonded to them. During this process the gore material is supported by tables adjacent to the tooling. The placement of the membrane on the tooling and its support during the bonding operation is all done by hand. The assembled portion of the reflector is then folded into bundles for ease of its movement away from the assembly area.

Handling of the completed 14-meter diameter reflector membrane structure is accomplished in a number of ways. The structure is transported by folding it into a bundle which can be placed in a container. Evaluation of the reflective surface precision and the operations involving its assembly with the canopy structure both require that it be unfolded into a planar configuration and tensioned around its perimeter. To accomplish this handling operation, a number of people ~~are located~~ around the perimeter of the membrane, apply very light loading at discrete points to (a) stretch the membrane so it can be mounted on a fixture, (b) position it for assembly with its canopy or (c) fold it after it attached its canopy for launch. These procedures worked well for the 14-meter diameter IAE reflector. It is estimated that these same procedures and processes will accommodate the manufacture of reflectors up to "on the order of" 25 meters in diameter. Beyond that point, new and semi-automated techniques will probably be required.

Ascent Venting

The ascent venting issues associated with these types of space structure were accounted for in the design of the IAE hardware. However, due to the lack of space flight experience with this specific type and size of inflatable space structure, the effectiveness of the techniques used was not really adequate. Increasing the effectiveness of IAE ascent venting technology, and/or the development of new techniques will be used for the next flight of this type of inflatable structure.

Torus and Strut Structure

The basic approach for ascent venting of the basic IAE support structure was to use bleeder cloth with TBD ______________ dimensions along the full length of the struts and torus. This cloth was attached to the end fittings that interfaced the struts with the torus and the struts to their pods. Simulation of the launch environment in the vacuum chamber using full-scale prototype hardware indicated that the gas flow path in the struts and torus was not nearly sufficient to bring the residual air down to the point required prior to orbital deployment. The bleed cloth was then replaced with flexible lanyards whose diameter was considerably larger than the thickness of the bleed cloth. Further simulations in the vacuum chamber using full-scale strut structures indicated that three lanyards were needed for each strut and the torus. The flight results showed improvement over the bleeder cloth approach, as evaluated in the chamber, but not enough to enable the deployment control desired. It is believed that the very high mechanical packaging associated with the struts in their individual pods resulted in high enough loading of the membrane against the lanyards to minimize the gas flow push around the lanyards. Additionally, it appears that there was enough residual gas in the MLI blankets, even though they were vented, to contribute to the deployment anomaly. A longer time in orbit prior to deployment would have significantly contributed to less residual gas in the stowed support structure and the lenticular structure.

Lenticular Structure

The basic approach used for venting of the lenticular structure was to incorporate several dozen, 1-mm diameter holes around the edge of the reflector structure. This approach appeared to be very simple and for a one-orbit experiment, the inflation gas loss would be trivial. However, on orbit there was still sufficient residual gas to cause "pillowing" of the entire lenticular structure as soon as its launch container was opened. It is believed that the compact packaging of the lenticular structure resulted in blockage of the vent holes from other areas of the membrane structure. This suggests that some type of large orifice values, that could be closed prior to deployment, may provide a more effective gas flow path. Another option would be the "vacuum pack" used in the Echo Balloon Series.

Deployment ~~Structure~~

The basic deployment scheme for IAE was based on ejecting the stowed reflector structure, as a package, away from its launch container prior to initiation of its own deployment. This way the inertially loaded reflector structure would essentially "pull" the struts out of their launch containers in a near uniform manner. When the struts ~~are~~ stretched to about 80% of their deployed length, a gas flow path ~~was expected to~~ develop and at that time inflation gas ~~will~~ be introduced to all three struts at their intersection with the canister structure. While the struts ~~are~~ being pulled from their pods, a low rate of deployment of the lenticular structure ~~will~~ be initiated from the release of strain energy from the inflatable materials ~~and the residual gas~~ in both the torus and lenticular structure. The plan was that when the struts were nearly completely deployed, inflation gas would be introduced to the already partially deployed reflector structure in order to complete its deployment.

On orbit the magnitude of residual gas in the stowed structure was significantly more than anticipated. As a consequence, the planned deployment sequence did not materialize. Instead, the reflector structured deployed prematurely so that its planned ejection away from the canister did not take place. By the time the struts migrated from their pods as a consequence of residual gas and material strain energy, the reflector structure was over half deployed. However, due to the robust nature of this type of space structure, the torus and ~~one~~ of the struts completed deployment at about the same time and complete deployment of the ~~other two~~ struts followed within a minute or two.

The results of the IAE strongly suggest that to achieve precise control of large inflatable structural elements, deployment control devices are required. Such devices would be integrated directly into support structures such as struts and toruses. A number of different types of control devices concepts have already been developed. A very promising approach would be to stow the structure around a mandrel so that its rate of deployment could be controlled by adjusting the gap that the flexible material pushes through. Deployment control of ~~canopy~~ THE LENTICULAR type structures is also required to prevent "billowing" of the membrane structure prior to complete deployment of its support structure. Techniques to consider might include (a) ascent venting with mechanical valves, (b) vacuum packing prior to launch and (c) a restraint system for the stowed reflector structure that releases to enable its deployment.

HIGH PRECISION MEMBRANE REFLECTURE STRUCTURES

The surface precision of the inflatable deployable membrane reflector structure is a function of many variables which include (a) the geometry of the flat gores that are assembled to produce the reflector, (b) the properties of the materials used for the gores, (c) the cutting of the gores from the as manufactured materials, (d) the handling of the gores, (e) the assembly of the gores and (f) the boundary condition of support for the reflector structure.

The procedures used for the IAE started with the selection of material which was 7 micron thick aluminized mylar. This material was available, in the thickness needed and had a low enough modulus to enable the required handling, processing and the assembly of the reflector. The determination of the gore shapes is done analytically. A L'Garde, Inc. computer code called FLATE solves the inverse problem of starting with the desired orbital shape, desired operating membrane stress and materials properties and calculates the unstrained flat gore shapes. The next step was to use the gore shape data as input to another L'Garde, Inc. Code called FAIM. This code accounts for all of the important manufacturing and assembly tolerances and then determines the reflector surface precision that can be expected for a given level of materials manufacturing and processing standards. This interactive analytical process is used until the projected surface precision is consistency with the design requirements.

The next step was the cutting of the gores, which was done with a computer controlled laser cutter. The required geometric precision of the finished gores was achieved to within ~~TBD~~ 200 MICRONS ________________. The gores were then folded, transported and aligned for assembly by hand. The gores were assembled, two at a time over curved tooling that represented the final reflector shape. The edges of the two gores were then butted together on the tooling so they could be joined together by the bonding of a tape doubler over both edges of the gores. As the gores were assembled, the completed part of the reflector structure was folded by hand into a long narrow bundle.

When the assembly of the reflector was complete, the determination of its precision was done by placing the reflector structure on a ring shaped fixture the same diameter as the structure. It was then stretched and attached to the fixture along its outer edge. Then the same pressure differential, planned for orbit, was applied to the edge supported membrane. The surface precision was measured with techniques. The surface precision achieved was on the order of 2-mm rms, for the portion of the reflector about a meter away from its edge. This is the portion of the reflector that would normally be used for actual RF operation.

The resulting surface precision of the as manufactured IAE reflector represented the level of technology available at L'Garde, Inc. during 1993. Subsequent to that time, a number of advancements have been made to a number of the technologies affecting the reflector surface precision. For example, the current NASA sponsored technology program at L'Garde, Inc. is contributing to even further advancements. Consequently, future applications of this technology can expect much higher reflector precision than demonstrated by IAE.

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The deployment control of each major structural element, including the canopy, is required to maintain high reliability. The orbital deployment was complete and successful due to the robust nature of inflatable deployable structures. The need for major improvement of ascent venting techniques was obvious and is currently being addressed. The low cost of these new types of space structure was demonstrated by building a large reflector structure for on the order of one million dollars. The outstanding mechanical packaging efficiency was demonstrated by stowing an antenna structure the size of the STS into a container the size of an office desk. The high surface precision of the membrane reflector structure validated procedures for the design, materials processing, and assembly for this type of structure. Since this reflector was the first of its type, modifications and/or refinements of the processes are expected to result in much higher precision reflectors. The successful development of this very large antenna structure validated the processes, handling and procedures used for manufacturing inflatable support structures and membrane reflector and canopy structures. The technology used for the experiment, validated by the experiment and the resulting requirements for the future development of technology represent the data base for this new class of space structures.

ACKNOWLEDGEMENTS

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IN-STEP INFLATABLE ANTENNA EXPERIMENT

EXPERIMENT DESIGN DESCRIPTION

PACKAGING CONFIGURATION

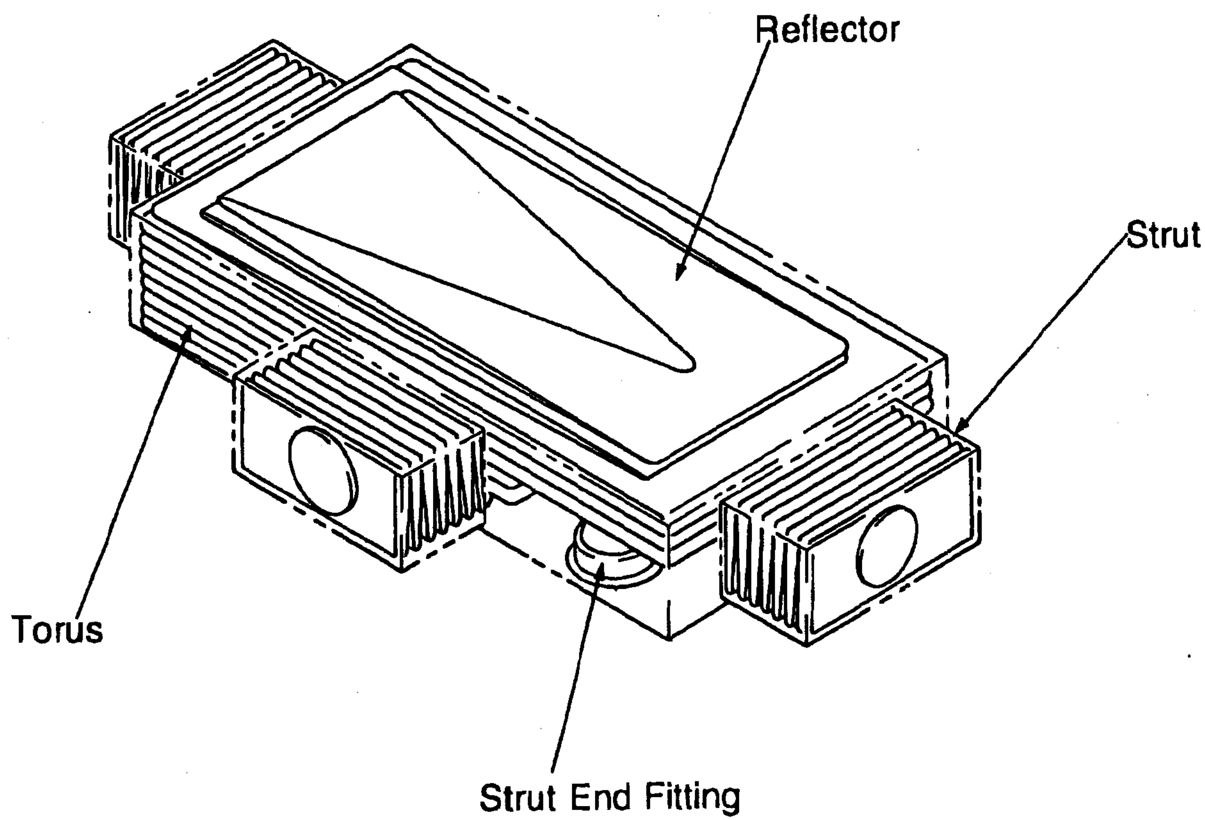


Figure 3

VU-94-GV-012

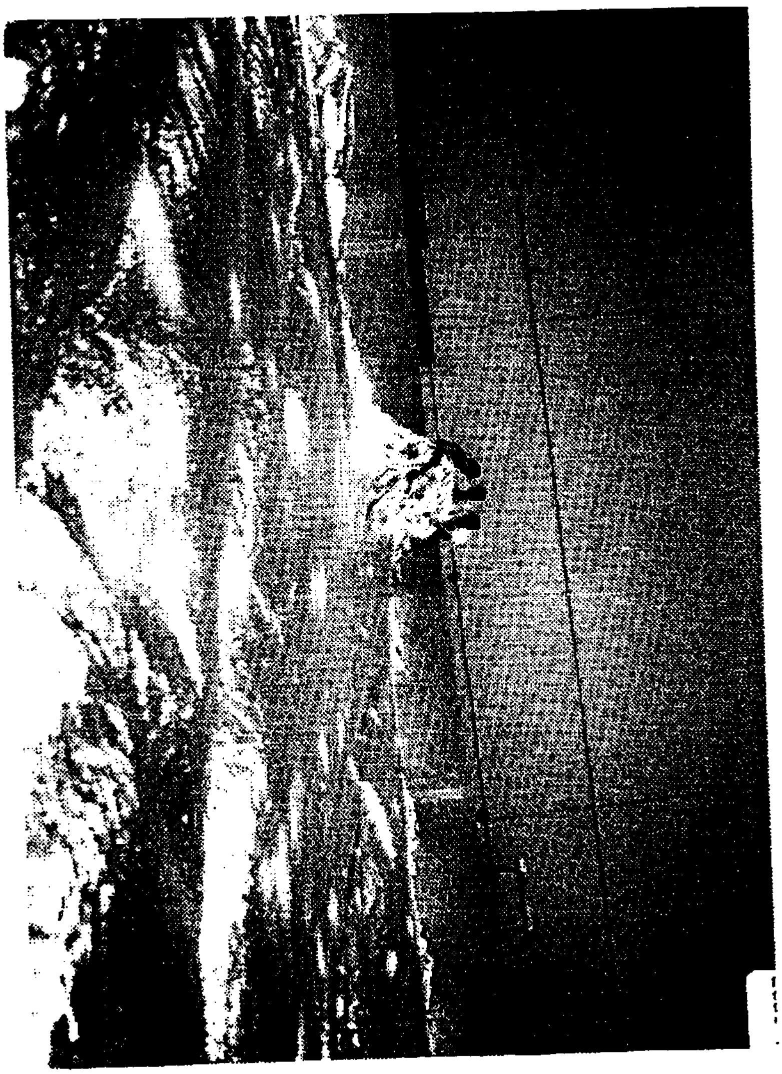
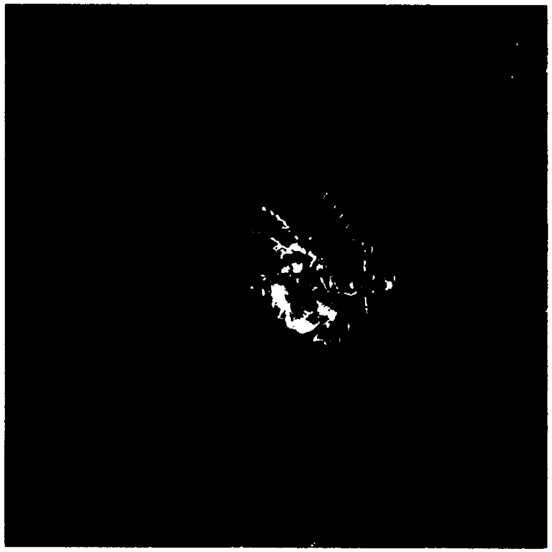


Figure 4

JPL

IAE ORBITAL DEPLOYMENT SEQUENCE



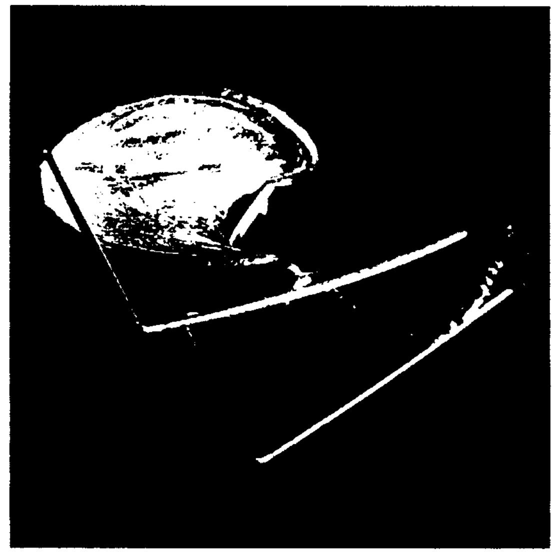


Figure 6b

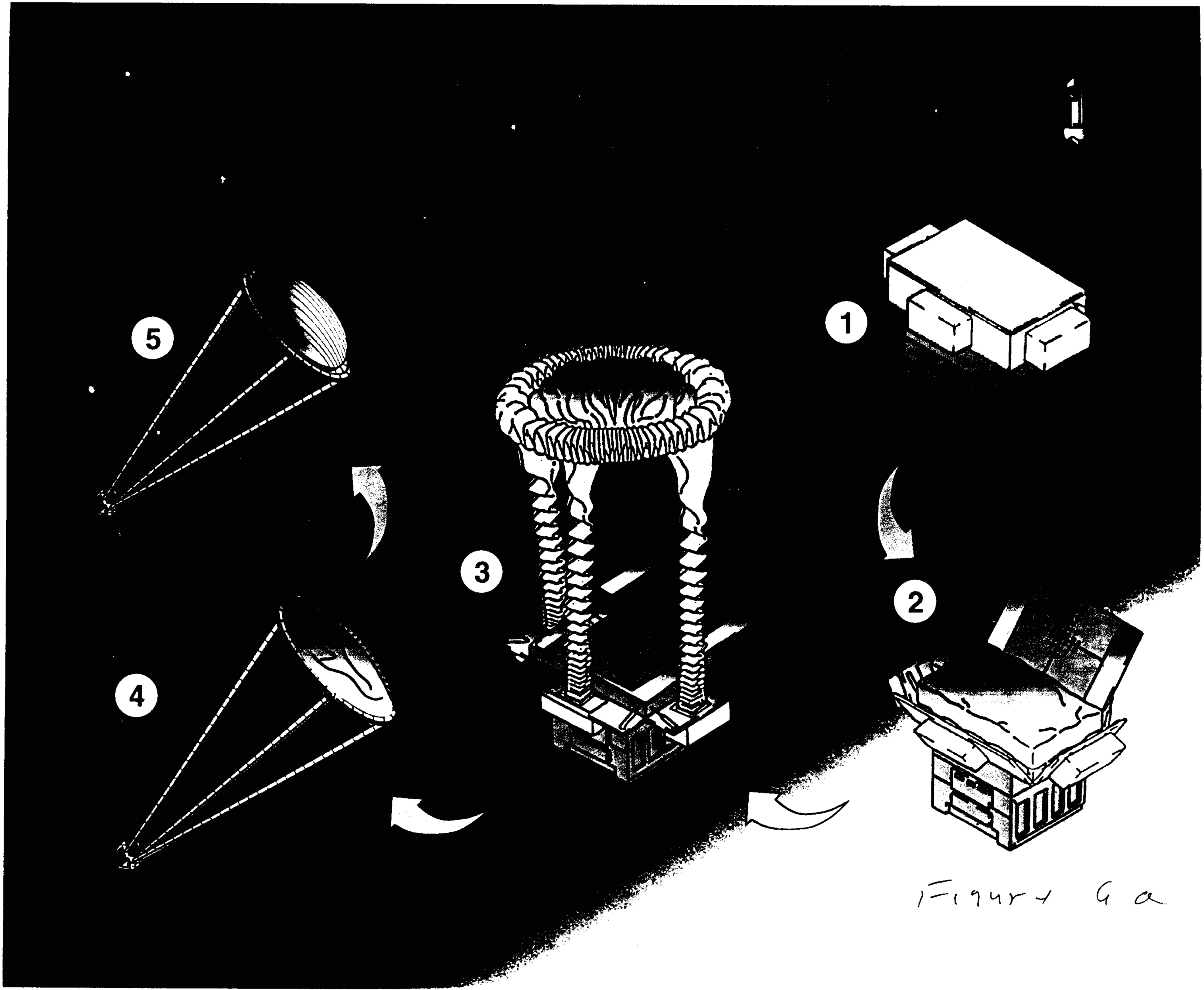


Figure 6a

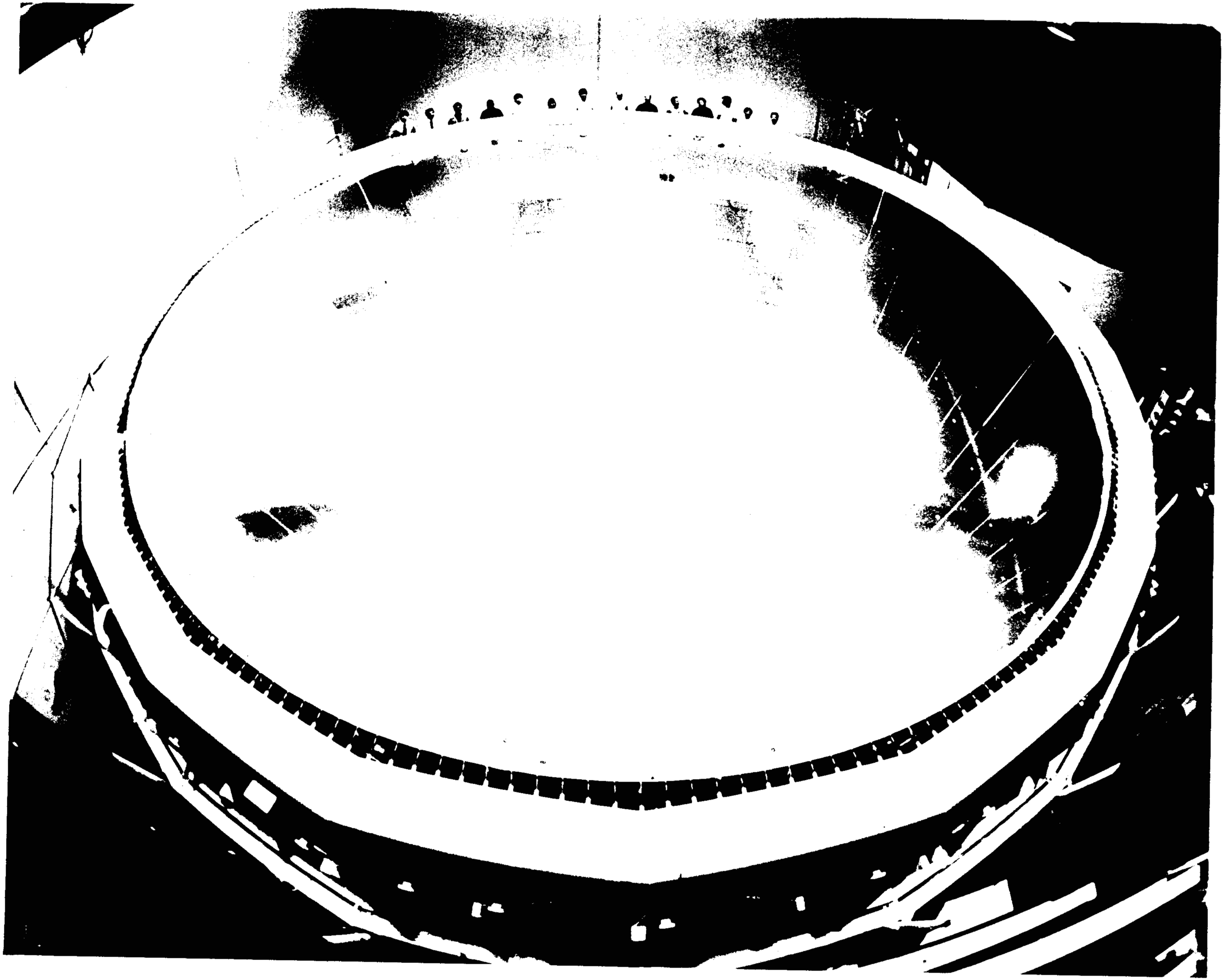


Figure 7