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CHAPTER 7

PASS SPACECRAFT ANTENNA TECHNOLOGY ASSESSMENT

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I. INTRODUCTION

The purpose of this assessment was to generate estimates of mechanical performance for the classes of spacecraft antenna under consideration for application to PASS. These performance data are needed for the support of trade studies involving antenna system development. The classes of antenna considered by the study included (a) rigid non-deployable antenna structures, (b) mechanical deployable antenna concepts, (c) inflatable deployable antenna concepts, and (d) mesh deployable antenna concepts. Several new industrial developments are in process for mesh deployable antenna technology in both the United States and Japan. They include the development of a high density RF reflector mesh, modifications of existing concepts to accommodate higher frequency applications and the development of new concepts. However, due to the limited data base for this class of structure, with capability for 20 to 30 GHz at this time, they were not included in the assessment. The estimates of mechanical performance are presented in terms of structural weight and cost as a function of the reflector size. Estimates of aperture surface precision are presented for a few discrete antenna sizes. The range of reflector size is 1 to 4 meters for non-deployable structures and 2 to 8 meters for deployable structures. The range of reflector surface precision is $\lambda/30$ to $\lambda/50$ for 20 and 30 GHz, respectively.

The data used to generate the performance estimates were obtained from (a) technical reports, (b) technical conference papers, (c) technical interchange meetings, and (d) industrial and government sponsored technical study results (References 1 to 14). The existing technical data base, for the specific antenna concepts, varies considerably with respect to the specific performance data needed for this JPL assessment. Such data are limited because they are based on actual hardware demonstrations, which result from different needs as compared to establishing a generalized performance characterization for the concept. Consequently, extrapolations and judgments were made, based on the available data, to establish the type of performance trends needed to support this system study. The reflector surface precision data represent only the as-manufactured capability and do not include the orbital thermal distortion or deployment repeatability error, for deployable concepts. The orbital thermal distortion is a function of the antenna configuration, materials of construction, spacecraft and mounting configuration, operational orbit and pointing attitude with respect to heat sources such as solar and earth albedo, and the deployment repeatability error is a function of the antenna kinematic configuration. However, all of the antenna concepts under evaluation utilize advanced structural composite materials which are known for their excellent thermal stability.

Therefore, it is reasonable to assume for most applications that the orbital thermal distortion represents only a fraction of the as-manufactured surface error.

The most difficult aspect of the study was to obtain current and well defined hardware cost data because of all the possible variables associated with a single cost figure. For example, the cost for a specific antenna reflector structure is influenced by factors such as (a) the level of technology of the concept, i.e., is the cost associated with the first, second or twentieth piece of hardware ever produced, (b) the number of units produced with the same manufacturing set up and tooling, (c) in addition to the flight unit, is there an engineering model, proof test model or flight spare antenna, (d) for deployable antenna concepts what level of ground based demonstration of deployment reliability is required in addition to delivery of the flight unit, (e) how does the design of the antenna structure vary from previously manufactured antennas, (f) how tight is the scheduling associated with the procurement, and (g) what is the level of qualification testing associated with the procurement?

The mechanical performance projections are intended to accommodate RF system trade type studies. They represent realistic relative differences between types of antenna structures and variations of the same concept. However, they should not be used for estimating specific hardware costs because of all the variables associated with a specific procurement.

II. NON-DEPLOYABLE ANTENNA REFLECTORS

The data presented for solid reflectors represent the manufacturing capability of at least 6 commercial organizations. The reflector size range of hardware utilized for the study is from 1.0 to 4.0 meters. The structural configurations associated with this class of reflectors fall into two categories. One is a honeycomb sandwich shell of uniform thickness (Figure 1). The other is a thin sandwich honeycomb or composite shell that is supported by rings or some type of rib stiffeners. Figure 2 is an example of a rib stiffened structure. This technology is very mature, has extensive flight experience and is "off the shelf" for most "standard" reflector shapes. The materials used for this class of structure include graphite/epoxy, kevlar/epoxy and fiberglass/polymer. Variations of these materials to accommodate specific application requirements are state-of-the-art. A major schedule driver for the production of this class structure is the tooling. An unusual shape or unusually large reflector might take considerably longer to acquire the appropriate tooling.

The non-deployable structure, without question, represents the highest reliability approach structurally for spacecraft antennas. However, there are some drawbacks to using solid antenna reflector structures in the large size ranges of 3 to 4.5 meters. Such large structures tend to dwarf the spacecraft, especially the small size spacecraft often used for communications applications. This situation results in difficulty in (a) access to the spacecraft hardware,

(b) spacecraft ground handling, (c) ground transportation, and (d) launch vehicle integration. Also, due to its size alone, such an antenna is subject to damage from a variety of sources, such as transportation, spacecraft assembly and servicing in the vicinity of the antenna, etc.

The reflector structure as-manufactured surface accuracy, associated with each piece of hardware considered in the survey, represented what was needed for a specific application and usually did not represent the best manufacturing capability for the concept at the time of manufacture. A surface accuracy of 0.2 mm rms, which represents an allowable surface error of $\lambda/50$ for 30 GHz, has been demonstrated with a significant number of structures up to 3.5 meters in diameter. This level of surface quality is not expected to be a problem with any of the solid antennas under consideration for PASS. Reflector structure weights and manufacturing cost as a function of size are given by Figures 3 and 4.

III. MECHANICAL DEPLOYABLE ANTENNA REFLECTORS

The data presented for mechanical deployable reflectors are based solely on the TRW Sunflower and the Dornier DAISY structural concepts. Both concepts utilize rigid, high precision, doubly curved, light weight panels that are kinematically connected to accommodate the automated deployment of such stowed elements (Figures 5 and 6, respectively). Both concepts were conceptualized for reflectors up to about 10 meters in diameter. The Sunflower is intended for operation up to 60 GHz passively for sizes up about 11 meters. Active orbital adjustment capability would increase the upper usable frequency by 50%. The DAISY is designed to operate at wavelengths of a hundred microns at sizes up to 8 meters passively. Neither concept is intended for orbital surface correction at this time. The data base for both of these concepts is very limited because of the small number of detail designs and demonstration hardware models fabricated for either of these concepts. The Sunflower has been developed to the point of (a) 2.5 meter partial deployable antenna consisting of the center panel and 4 out of 16 deployable petals, (b) fabrication of 3 meter panels for a 10 meter antenna, and (c) analytical estimates of orbital thermal performance for all size structures. The DAISY concept was initially developed for FIRST, a European Space Agency (ESA) 8 meter diameter space based submillimeter telescope. This concept has been developed to the point of a 5 meter engineering model with an F/D of 0.64 and an as-manufactured surface precision of 60 μ m rms. It is intended for communications applications at 20 to 30 GHz. The potential surface precision of either concept, especially in the small size range, really exceeds the requirements of PASS. This class of deployable structures, because of its deployed stiffness lends itself to meaningful ground based demonstrations of deployment reliability and surface precision. The Sunflower is currently mature enough to accommodate near term flight applications. The DAISY is expected to be developed to the point of flight applications within a year or two.

IV. INFLATABLE DEPLOYABLE ANTENNA REFLECTOR

The data base for this antenna concept is based solely on the Contraves Inflatable, Space Rigidized Structural Concept. It is a relatively new and extremely innovative structural concept. This concept development is sponsored by ESA/European Space Research and Technology Centre (ESTEC). The concept is based on using a flexible thin wall structural composite membrane that is assembled on high precision tooling fixturing that simulates the geometry of the deployed structure. This membrane, as a consequence of its flexibility, allows the structure to be folded up and stowed in a variety of configurations, not unlike a life raft or emergency chute on an airplane. The antenna is deployed on orbit by inflation of the membrane structure. Once inflated to the orbital operational configuration, the solar heating causes the rubber-like matrix material to cure and become a rigid shell type structure. The load carrying fibers in this composite material are kevlar. The inflation gas is then released, leaving a permanently rigid space structure (Figure 7). The potential advantages of this concept include (a) excellent mechanical packaging efficiency, (b) high deployment reliability, (c) low weight, especially in the larger sizes, and (d) low cost compared to mechanical concepts. The initial development for this concept was focused on a 15 meter, 22 GHz antenna intended for earth orbiting Very Long Baseline Interferometry (VLBI).

However, recent developments have been focused on an off-axis multiple beam communications antenna application. The current as-manufactured reflector surface precision is on the order of 0.6 mm rms for proof of concept structures up to 6 meters. This number is currently well below the surface precision requirements for PASS, but this concept is still under development and each successive hardware demonstration model has shown significant improvements. Therefore, if the assumption is made that this type of improvement will continue, especially for the small size structures, this concept has real potential for PASS. This new and extremely unique concept should be considered a prime candidate for concept development, specifically for PASS. Figures 3 and 4 represent the latest estimates of performance for this concept in terms of the structural weight and manufacturing cost as a function of size.

V. CONCLUSIONS

1. Rigid, non-deployable reflector structures technology can easily accommodate PASS antenna requirements for structures up to about 4 meters.
2. Current mechanical deployable antenna technology can accommodate PASS antenna requirements for reflectors up to 8 meters but with (a) substantial weight and cost penalties and moderate scheduling penalties as compared to the use of rigid structures in the size range up to 4.5 meters, and (b) weight and cost penalties as compared to inflatable structures in the size range 4 to 8 meters.

3. The inflatable deployable antenna concept evaluated has the greatest potential for accommodating PASS antenna requirements at low cost. However, additional technology development will be required to demonstrate its true value.
4. As technology for PASS matures, it is anticipated that the need for larger size antenna reflectors will materialize.
5. As the size of the antenna reflector increases, especially with respect to small size spacecraft, the importance of working with manageable size spacecraft that require minimal booster payload volume will become even more apparent.
6. When the size of the reflector needed for PASS exceeds the dynamic envelope of the booster payload compartment, then deployable antennas will become mandatory.
7. Since the probability of needing deployable antennas for PASS in the near future is high, serious consideration should be given at this time to (a) adopting existing deployable antenna concepts for PASS, (b) developing new and innovative antenna concepts specifically for PASS, and (c) supporting the innovation of really new antenna concepts for applications not efficiently accommodated by today's technology.
8. Subsequent to this antenna technology assessment a number of industrial sponsored antenna concept developments have been initiated. Consequently, it is recommended that additional evaluation of these "new" developments be made prior to the formulation of a technical development plan for submission to NASA Code E.

It is noted that, subsequent to the completion of the PASS Spacecraft Antenna Technology Assessment, a significantly more in-depth survey was accomplished that focused on commercial IR & D developments of proprietary spacecraft antenna concepts. Consequently, the resulting report, "PASS Spacecraft Antenna Technology Study," is intended only for government use, and distribution will be based on written requests to the authors from authorized government agencies.

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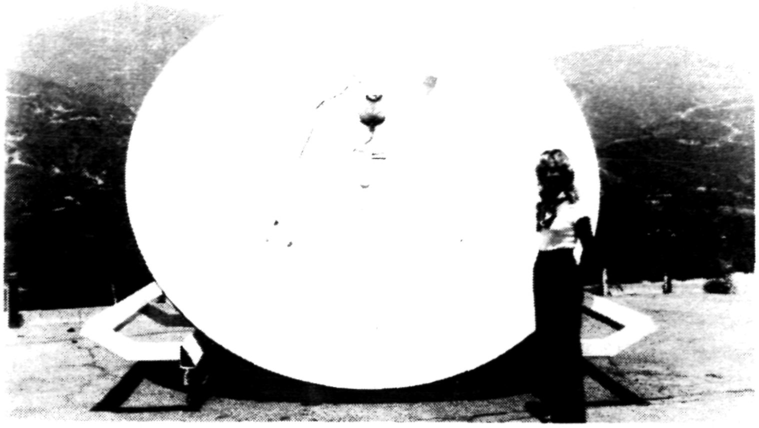

Figure 1. Composite Sandwich Reflector Structure

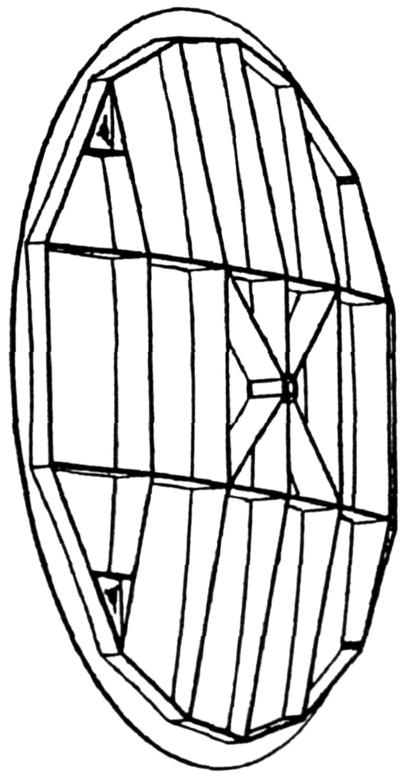

Figure 2. Rib Stiffened Composite Sandwich Reflector Structure

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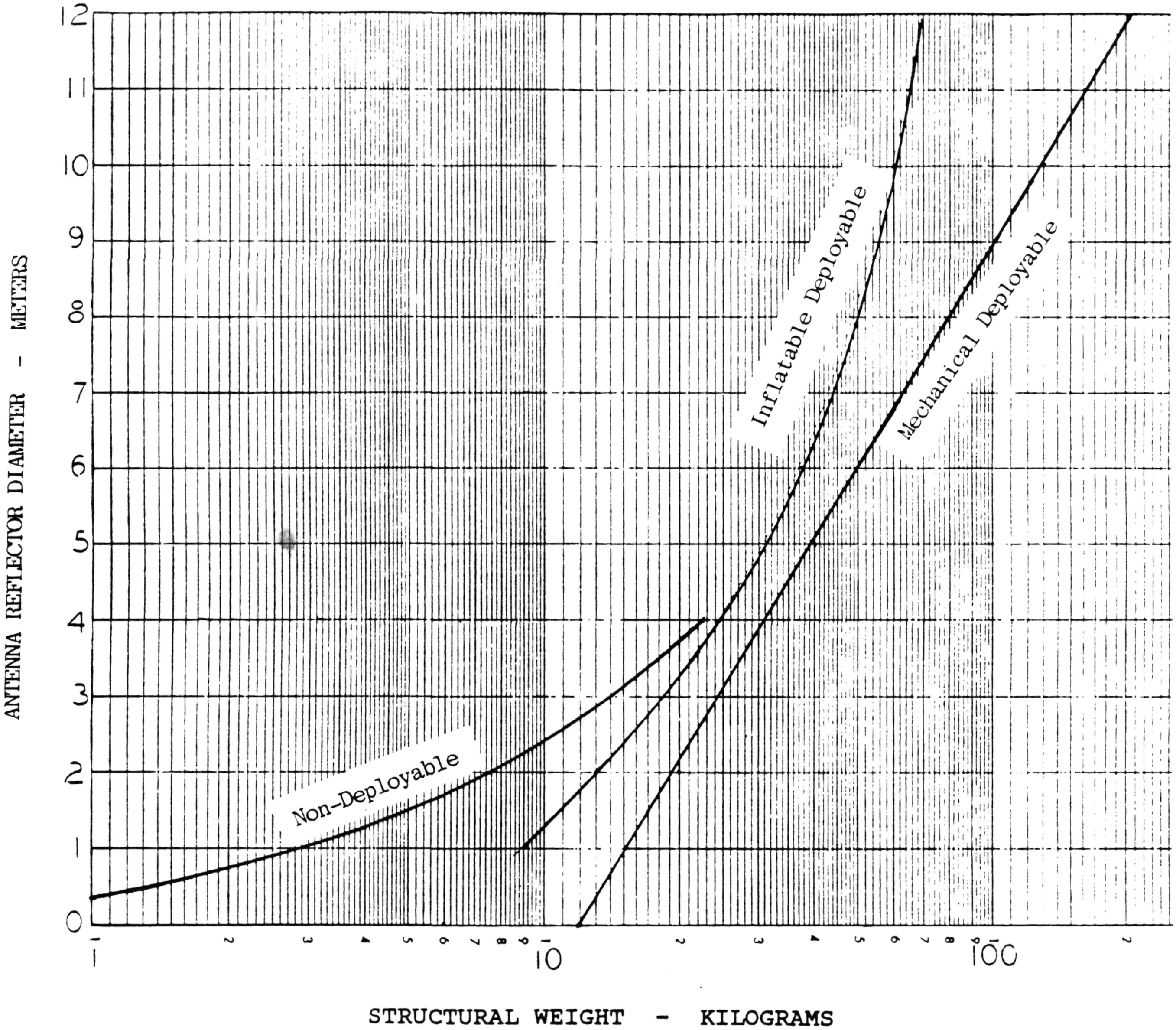


Figure 3. Antenna Weight vs. Size

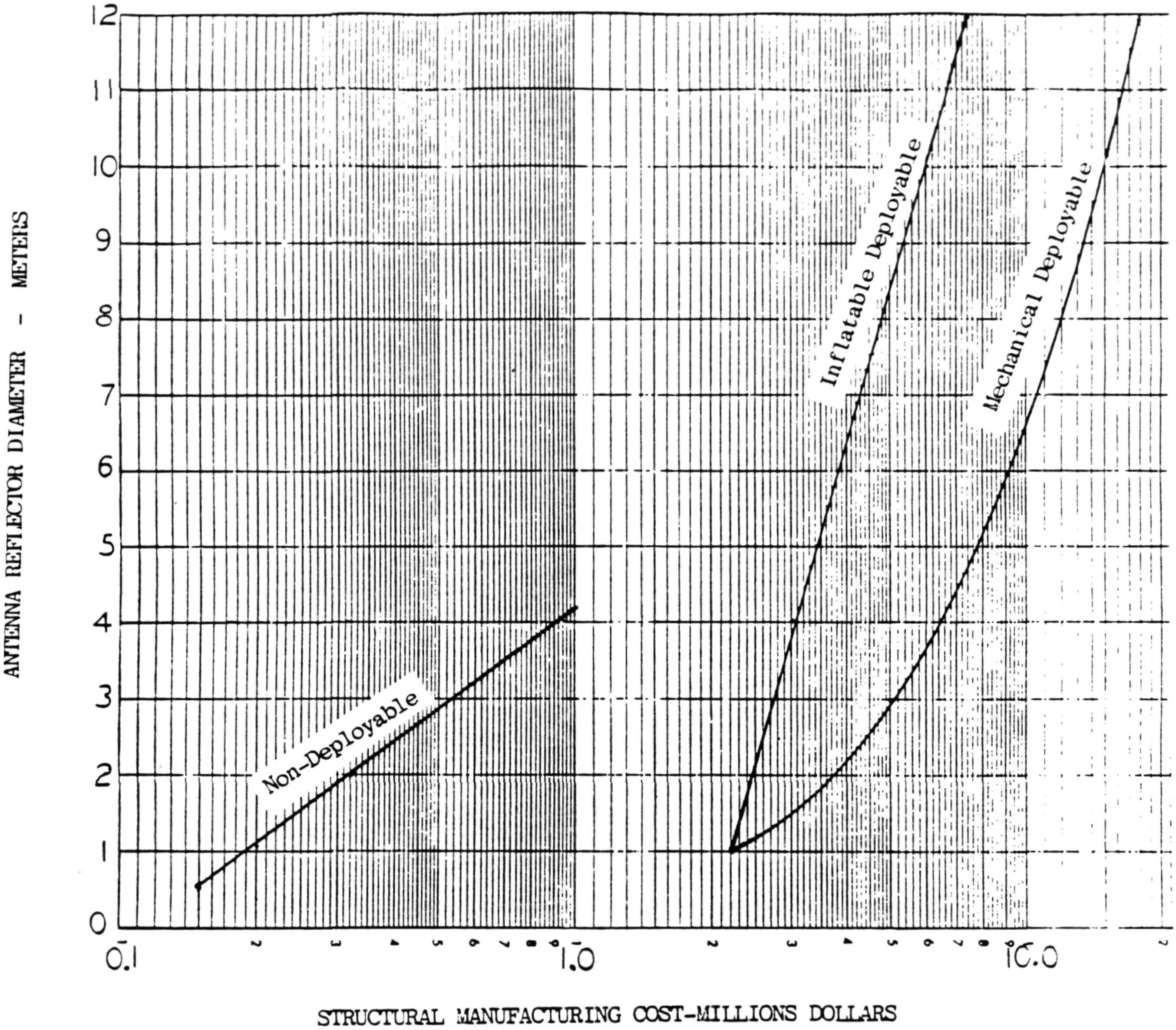


Figure 4. Antenna Cost vs. Size

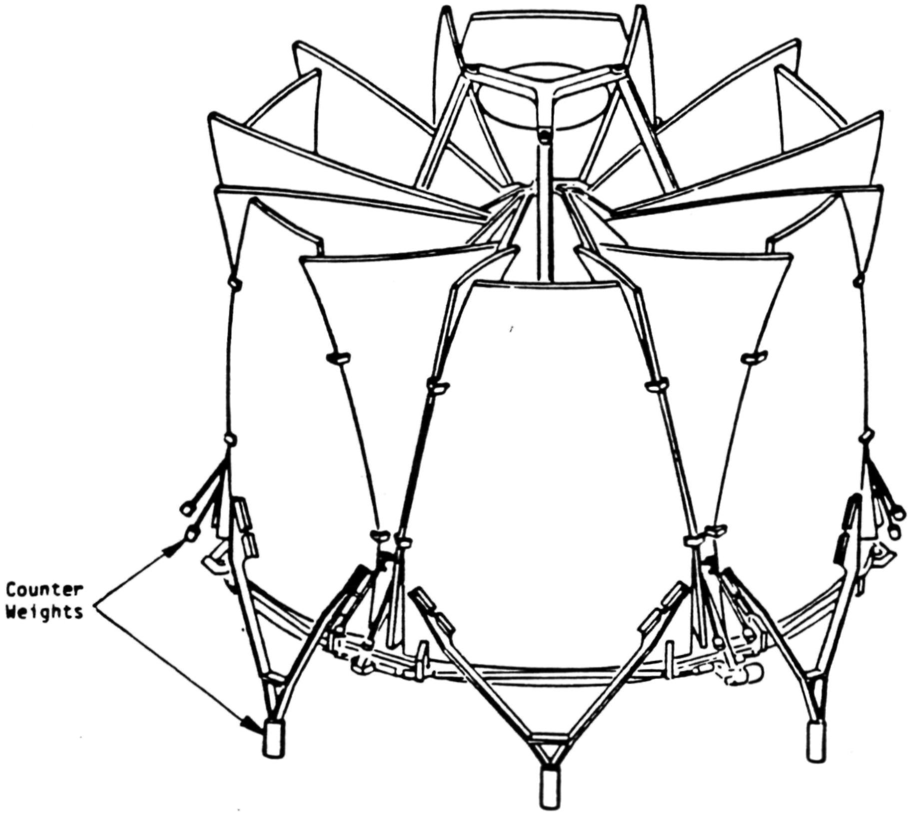


Figure 5. Sunflower Deployable Reflector Antenna

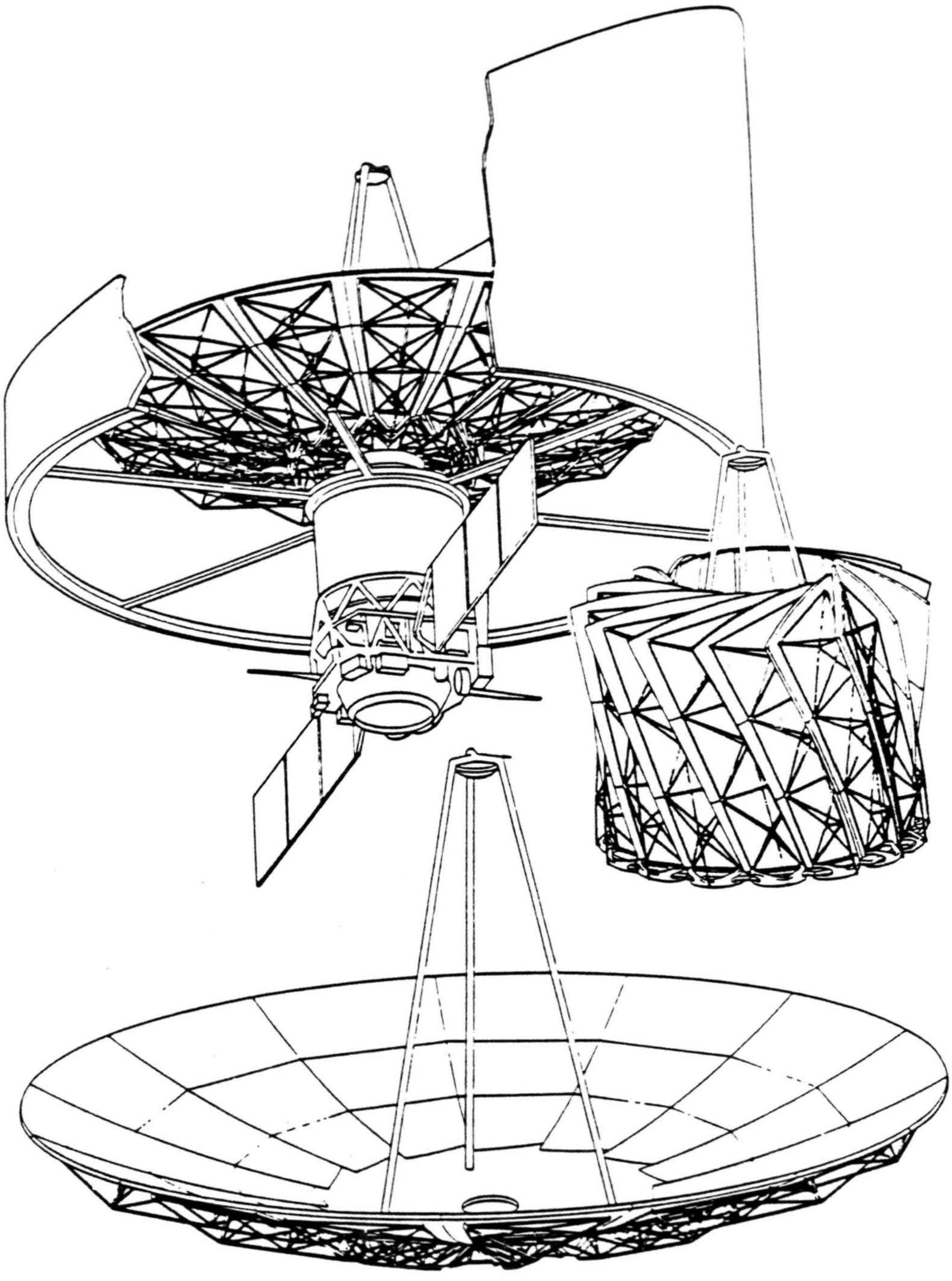
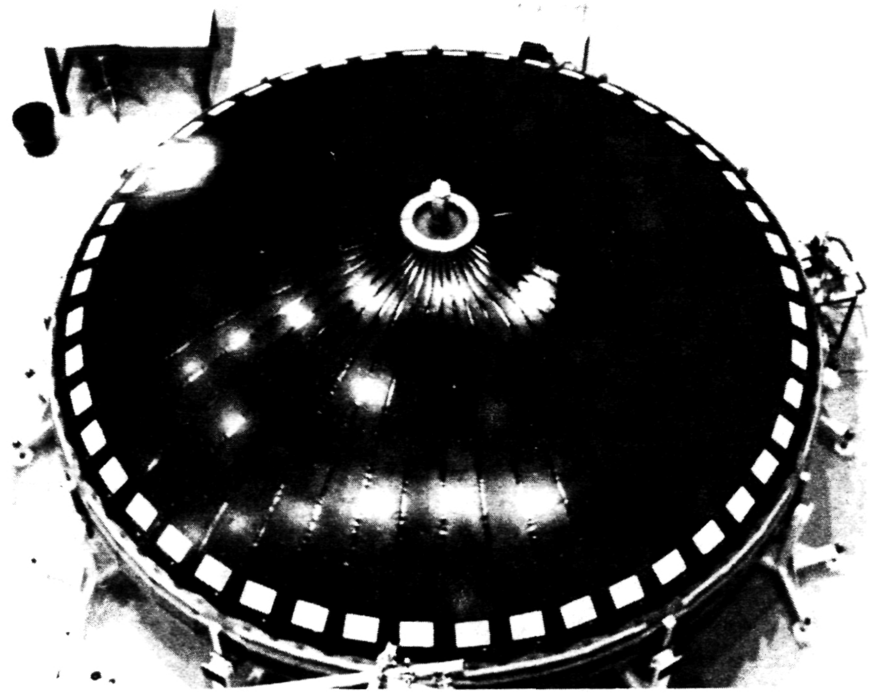
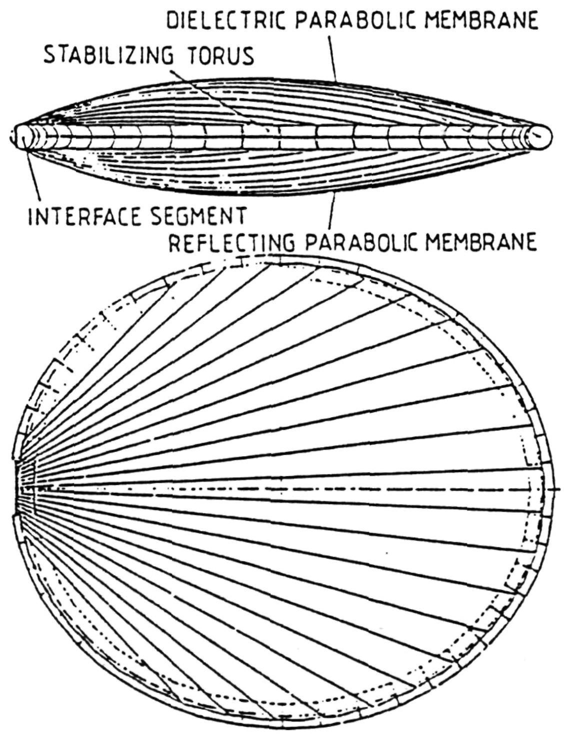


Figure 6. Daisy Deployable Reflector Antenna



(a) 6-m Axis Symmetric Hardware Demonstration Model



(b) Concept for 5-m Offset Reflector

Figure 7. Contraves Inflatable Space Rigidized Antenna