S9-32
219955
158

ADVANCES IN LARGE INFLATABLE REFLECTORS

N90-19258

M. Thomas and G. Williams
L'Garde, Inc.
Tustin, CA

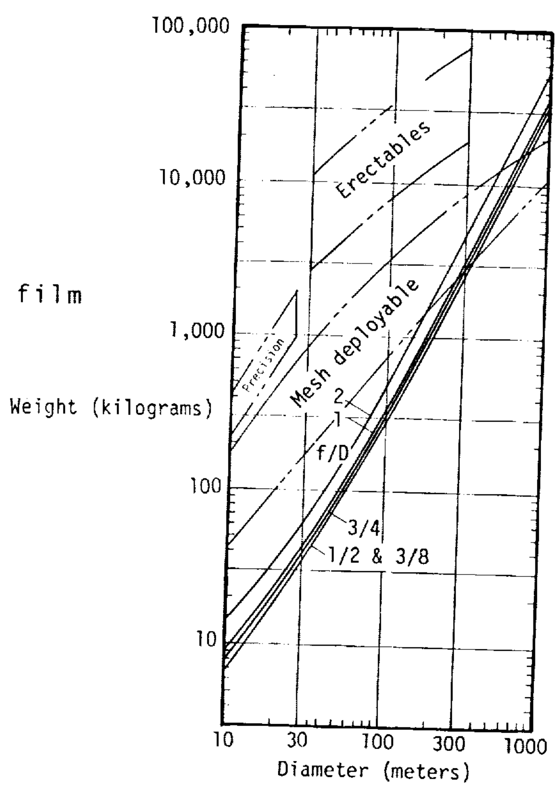
Weight of Inflatable Antennas

For most applications in space for which they have been tried, inflatable structures show a significant weight reduction when compared to mechanical structures. The curves shown here for mechanical structures were compiled from a JPL report by Freeland (Reference 1) based on an industry survey of projections for weights of large antennas. The curves for inflatable antennas were produced by us during a 1983 NASA funded study (Reference 2). For this study only wavelengths longer than 1 cm were considered. The inflatables showed a large projected weight savings over even mesh deployables until very large diameters were desired (greater than 300 meters). These curves were based on using films routinely available off the shelf. Note that the curves begin to diverge upward from the straight line at lower diameters. The weight of such systems strongly depends upon the inflation pressure, since make-up gas is carried in the weight budget to allow for leakage over the projected ten-year life of these structures. The inflation pressure must be increased to provide sufficient stress in the film to remove packaging wrinkles if precision structures are needed (wavelengths shorter than 1 cm). This also increases the weight of the torus used to support the membrane due to the increased loads. For mm wavelengths, the weight of such structures at diameters in the ten meter range can be increased by a factor of ten if high precision is required.

1. Freeland, R. E., Industry Capability for Large Space Antenna Structures, Report 710-12, Jet Propulsion Laboratory, May 25, 1978.

2. Friese, G. J., G. D. Bilyeu and M. Thomas, Initial '80's Development of Inflated Antennas, NASA Contractor Report 166060, January, 1983.

0.006mm (1/4 mil) film



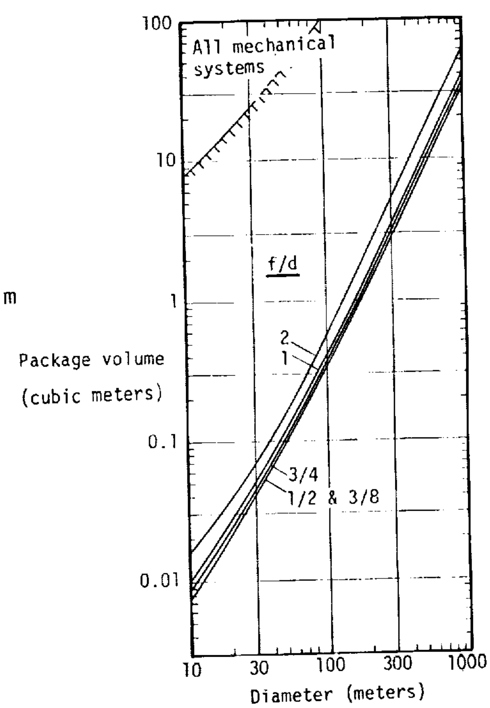
Packaged Volume of Inflatable Antennas

Inflatables are unmatched when compared to mechanical structures when packaged volume is considered. Furthermore, inflatables can be easily packaged in rather bizarre shapes to make use of available volumes. This flexibility is particularly important for space missions, since most shuttle payloads have been volume limited rather than weight limited. This figure shows the many orders-of-magnitude improvement in packaged volume available by using inflatables.

As for the previous weight chart, the data shown here was generated for relatively long wavelength electromagnetic radiation, and a factor of ten increase in required volume may be necessary at the lower diameters, if precision structures are needed. However, even for such an increase, the inflatable approach clearly provides a superior packaged density. Previous calculations have shown that a 700 m diameter microwave antenna could be carried into orbit by a single shuttle flight, if the antenna were an inflatable.

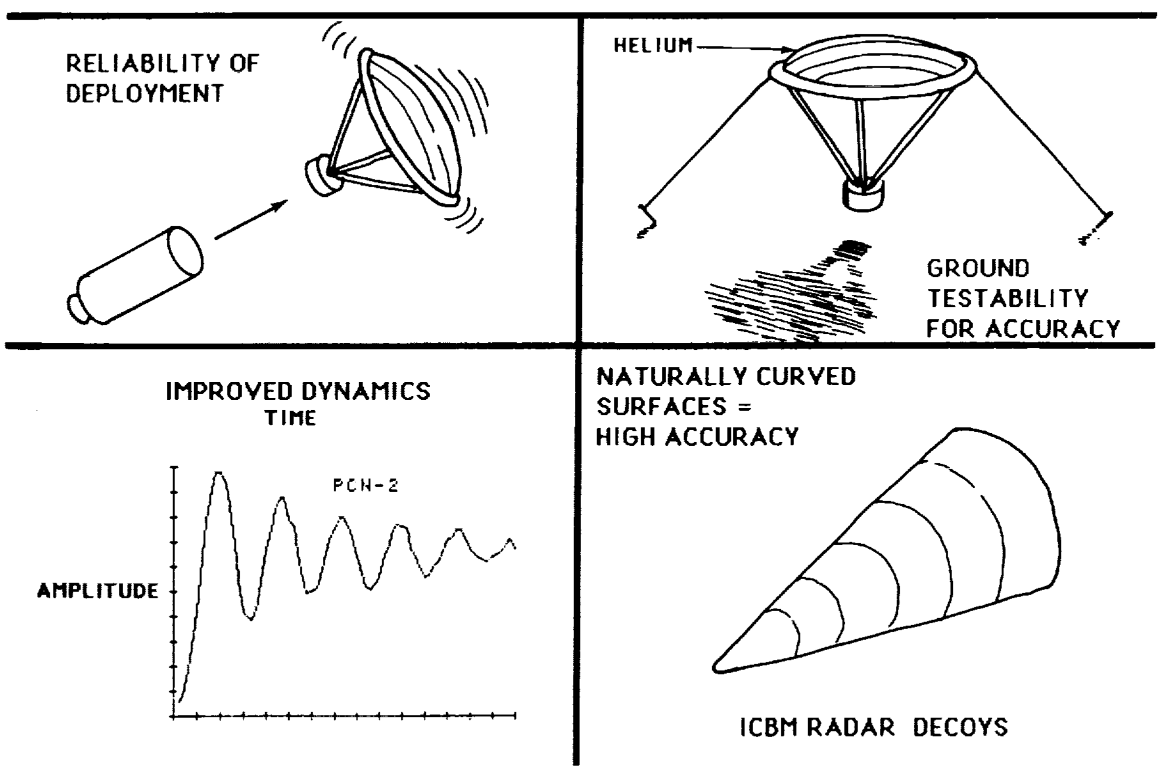
These calculations were performed for a 10 year life in orbit and wavelengths longer than 1 cm.

0.006mm (1/4 mil) film



Other Advantages of Inflatable Antennas

The reliability of deployment of inflatable structures has been known for years. When properly designed, such a system is inherently more reliable than mechanically erected structures simply because it has very few points of failure. Furthermore, the deployment forces are distributed over large areas resulting in less local build-up of high forces. The structural strength of the ECHO satellites was evaluated by NASA in a zero-g environment created by inflating the satellites with a lighter-than-air mixture so that it floated in the laboratory. Similarly, an inflatable antenna is the only lightweight large space structure whose accuracy can be checked on the ground by using such a technique. The dynamics of inflatable structures are improved over mechanical systems because (1) the damping coefficients of typical thin films result in energy losses per cycle due to hysteresis hundreds of times greater than for typical high strength composites or metals, (2) the resonant frequencies of a large inflatable are dependent on inflation pressure, so another variable can be introduced into the structural design to adjust such frequencies, and (3) many of the distortions that motion induces into an inflatable fight a constant inflation pressure resulting in motion that is not simple harmonic and has no resonances at all. Another advantage of the inflatable that has been proved in many studies of USAF decoy systems is that the inflatable, being formed by a pressure over the surface, can naturally assume curved shapes, making precision easier to accomplish than with mechanical systems.

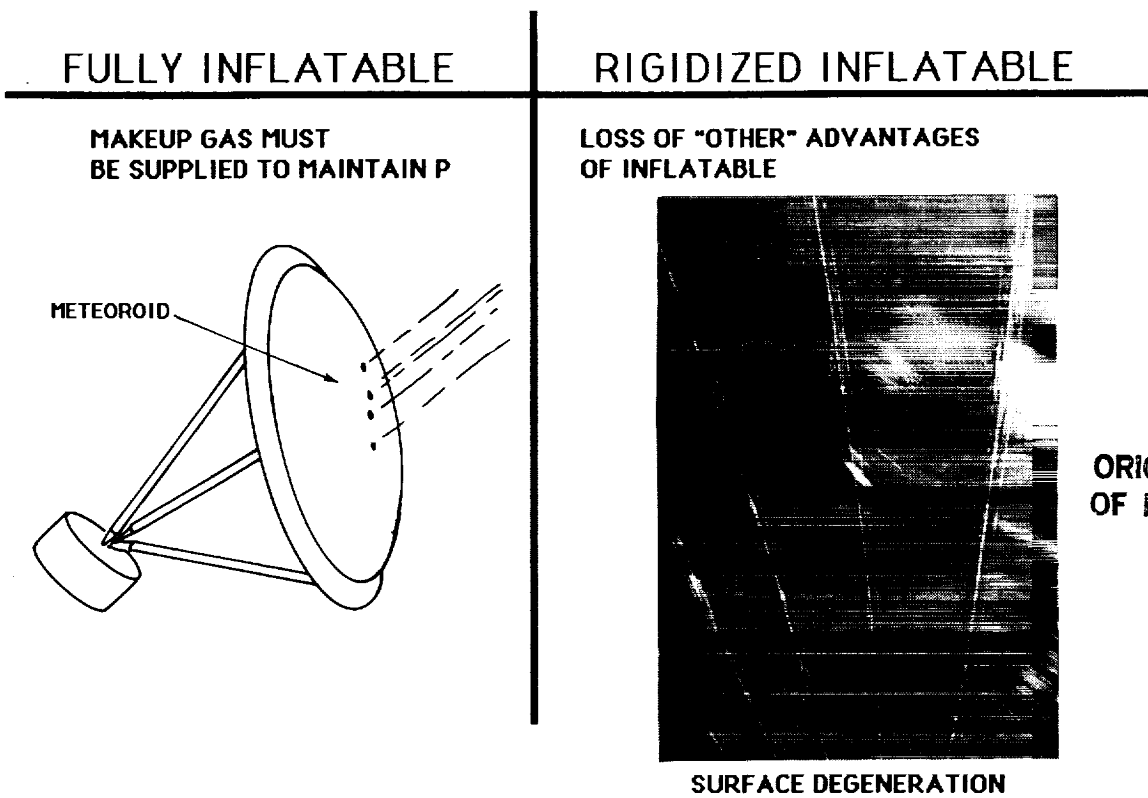


Fully Inflatable vs. Rigidized Inflatable

In the ECHO days, concern for meteoroid penetration led to a change in the emphasis of NASA inflatable research from pure inflatables to structures that deployed using inflation but were then rigidized. However, the meteoroid flux was overestimated by three orders of magnitude (1000) in those early days. Furthermore it was not generally understood that the larger the structure, the lower the required pressure, so that structures large enough can be kept fully inflated by carrying along make-up gas to compensate for loss through holes, and the weight of this gas would be insignificant. Thus, fully inflatable antennas again became a viable option.

Clearly if the weight of a fully inflatable including the make-up gas is less than the weight of an inflate-then-rigidize structure, the fully inflatable is preferred unless some other consideration enters. A rigidizing structure will be clearly less reliable since an additional mechanism is involved, and many of the advantages of the inflatable are lost--such as the ability to accurately measure performance on the ground, and improved dynamics. Furthermore, the act of rigidizing the inflatable requires new surface forces that are of the same order or higher than the inflation forces. As a result, the high-accuracy obtainable in the inflatable will be degraded.

The fully inflatables are generally the preferred structure for very large precision structures. The rigidized inflatables are preferred for small-volume structures where precision is not necessary. An inflatable antenna may be a hybrid, using rigidized components to provide structural support and mountings, and a fully inflatable to provide the reflecting membrane.



L'Garde Solar Concentrator Experience

Under the Highly Accurate Inflatable Reflector (HAIR) program for the Air Force Astronautics Laboratory, L'Garde has performed extensive experimental work leading to the development of these large inflatable reflectors for the solar rocket system.

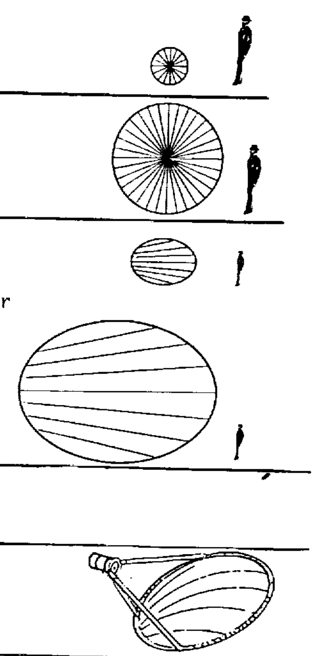
In the first phase of this Small Business Innovation Research (SBIR) contract (F04611-83-C-0051) analytic and experimental studies showed that inflatable reflectors could be made with surface errors less than 0.1mm RMS. In the second phase of the contract (F04611-84-C-0054) a 3 meter diameter concentrator was built with less than 3 milliradians (mrad) RMS slope error. In addition, an inflated torus was built and attached to the two membranes (reflector and canopy) and testing of the rigidized aluminum truss cylinders was performed.

A follow-on AFAL contract to HAIR, the Deployable Solar Concentrator Experiment (DSCE) is now in progress (F04611-86-C-0112). In this program, subscale <u>off-axis</u> reflectors, such as those used on the solar rocket, are being developed. The first 2 x 3 meter membrane has been built and tested with good results--a 3 mrad RMS slope error. An upscaled 7 x 9 meter reflector will be built and tested next.

In parallel to the HAIR/DSCE ground test programs, L'Garde is performing a flight testing program, the Space Inflatable Reflector Experiment (SIREX). Phase I (F04611-86-C-0054) was a preliminary design/planning contract, while the current Phase II Program (F04611-87-C-0072) will take the flight test hardware all the way through development testing.

A new contract from NASA-Langley is the Inflatable Solar Concentrator Experiment (ISCE). This project will define space experiments to determine structural damping, materials survivability, and inflatant requirements.

HAIR I (AFAL)	1984	o One meter 0.1 mm accuracy
HAIR II (AFAL)	1984 - 1986	o Three meter 3 mrad error
DSCE (AFAL)	1987 - 1991	o 2 x 3 meter 3 mrad error o 7 x 9 meter-1mrad goal
SIREX I (AFAL)	1986	o Space test plan
SIREX II (AFAL)	1988 - 1991	o Space test hardware
ISCE (NASA-LaRC)	1988	o Define space experiments



Off-Axis Reflector Test Set-up

Shown in this figure is the test set-up for laser mapping the surface. The membrane is mounted to an elliptical aluminum ring on the wall. A vacuum is drawn on the rear side to pull the film into a parabolic dish. A laser is mounted to a steel structure (to the left of the photograph) and can traverse left-right and up-down to impinge on any portion of the reflector. The beam is then reflected to a target mounted on the adjacent wall for data collection. Shown is the first membrane built. The data have been recently reduced and yielded a 3 milliradian RMS slope error.

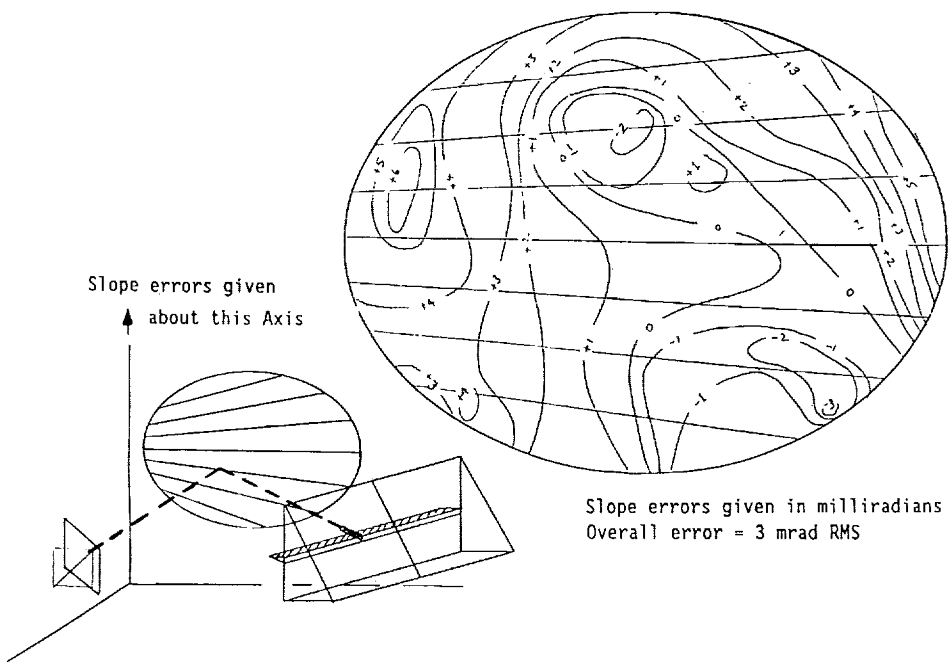
The goal under the current DSCE contract is to build an upscaled 7 x 9 meter off-axis reflector with an RMS slope error less than 1 milliradian.

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

Surface Mapping

The data for the 2 x 3 meter reflector is shown below. The contour map shows lines of equal slope error (in milliradians) about the axis shown. Slope errors are highest near the edges. The valley in the lower right-hand corner was due to a small tear in the membrane. A patch was placed over the tear, but still shows a slight stiffening effect.

The map is a result of running the laser from right to left at five different heights. The target (where the reflected beam hits) is shown at the left of the sketch below.



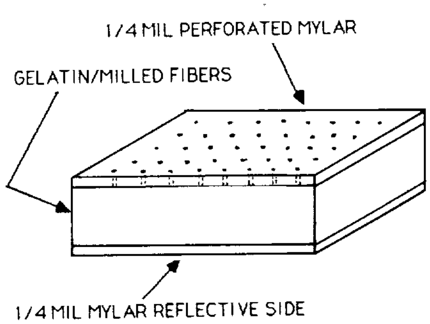
ORIGINAL PAGE IS
OF POOR QUALITY

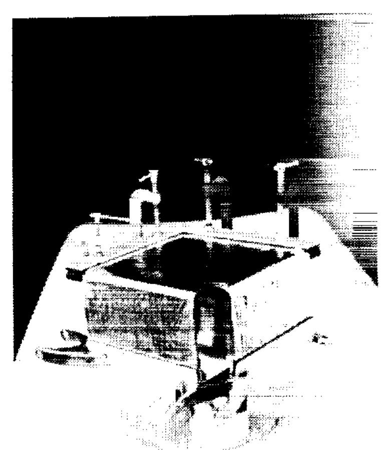
Reflector Surface Rigidization

For some space applications, the fully inflated reflector is less than desirable, mainly due to an extreme make-up gas requirement. This can happen in several instances: The reflector is exposed to a severe debris environment, the inflation pressure is high in small reflectors, or there is not a severe requirement on surface accuracy.

L'Garde has attempted to rigidize the parabolic dish reflectors by applying Fiberglas cloth/resin to the back of an inflated dish. The problem here was in surface degradation; the fabric showed through the film. More recently, L'garde has done some subscale testing on a new method. Rather than using a fabric with a regular pattern that can show through the film, individual fibers are mixed with gelatin to form a thick resin layer between two layers of film. The top film is perforated to allow the water solvent to escape, while the bottom (reflector) layer is non-perforated. While the preliminary tests have yielded poor results due to excessive gelatin shrinkage, the development is continuing.

- NEED FLAT SURFACE FOR REFLECTIVE FILM
- FABRIC "SEE-THROUGH" PROBLEM
- RIGIDIZE WITH GELATIN/FIBER RESIN MIXTURE





ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

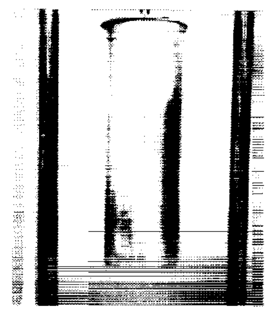
ORIGINAL PAGE IS
OF POOR QUALITY

Cylinder Rigidization

This figure shows three possible methods of rigidization for torus/truss applications. In the first, an annulus is constructed of thin aluminum foil (3 mil) and is initially folded and packaged. Upon deployment, the cylinder unfolds and the aluminum skin is stressed to its yield point by pressurization. The inflatant is vented and the cylinder performs as a thin-walled tube. The second method is similar to the first except that liquid polyurethane foam is injected into the deployed cylinder to provide greater resistance to compressive loading and buckling. The liquid foam expands into the cylinder and hardens. Finally, the third method uses a Kevlar fabric soaked with a water soluble gelatin resin, made into an annulus. When exposed to the vacuum of space, the water solvent evaporates making the cylinder rigid. This last method has shown great success as shown in the next figure.

PRESSURIZED ALUMINUM CYLINDER

- INITIALLY FOLDED
- INFLATE TO YIELD THIN ALUMINUM SKIN VENTED
- USE FOR TRUSS APPLICATIONS

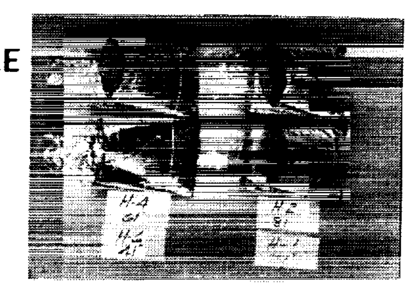


FOAM - FILLED CYLINDER

- INITIALLY FOLDED
- INFLATE TO REMOVE WRINKLES
- FILL WITH POLYURETHANE FOAM
- USE FOR TORUS (HIGH BENDING) APPLICATIONS

GELATIN/KEVLAR CYLINDER

- FABRIC INPREGNATED WITH WATER SOLUBLE GELATIN
- INITIALLY FOLDED
- INFLATE TO REMOVE WRINKLES
- ALLOW WATER SOLVENT TO EVAPORATE
- USE FOR TORUS OR TRUSS



Strength Comparison of Rigidized Cylinders

L'Garde has performed a series of tests on a number of rigidization techniques. The strength comparison for the different methods is as shown below. The superiority of the newly developed Kevlar/Gelatin composite is obvious from strength comparisons. Planned tests include inflation/rigidization in a vacuum chamber, bending tests, and outgassing tests.

The Scot Foam/Gelatin Method was included in this chart for comparison. In this method, spongy Scot foam is soaked in liquid gelatin and then allowed to dry to allow the gelatin to perform as the matrix. This method was quickly disregarded due to its poor performance.

Description	Maximum Compressive Load (lbs.)	Weight of 12" Cylinder (lb.)	Strength/ Weight (lb/lb)
Scot Foam w/gelatin	125	.37	330
Stressed aluminum foil	33	.046	720
Polyurethane foam-filled cylinder	650	.44	1,480
Kevlar/Gelatin	2,002	.28	7,140

Meteoroids

For the Government, we recently investigated the impact of meteoroids on inflatable structures. Although much earlier data had been obtained for the high velocity impact of small particles on rigid structures, little was known about similar impacts with thin films. A series of tests were run at the Arnold Engineering Development Center (AEDC) on typical materials using 200 micron diameter particles at velocities above 27,000 fps.

In general it was found that the resulting holes from these polystyrene microspheres were larger than that expected from a "cookie cutter" model, by about a 1.5 times diameter. Furthermore, the use of the thin films as bumpers was explored, and the effect of spacing on second surface penetration was found to be significant. These data are still being analyzed.

AEDC Hypervelocity Range S-1

DATA-SHOT PARAMETERS

DATE	TARGET MATERIAL	TARGET OBLIQUITY	SABOT VELOCITY (FPS)	# OF PARTICLE IMPACTS ON LEADING TARGET	REAR TARGET PERFORATION
2-3-88	2 mil Tedlar	0°	27,560	3	No
2-4-88	1/4 mil Mylar	0°	27,870	5	Yes
2-11-88	1/2 mil Mylar	0°	27,100	**	**
2-12-88	1/2 mil Mylar	0°	27,600	2	Yes
2-15-88	1/2 mil Tedlar	0°	27,910	3	Yes
2-16-88	2 mil Tedlar	45°	27,980	3	No

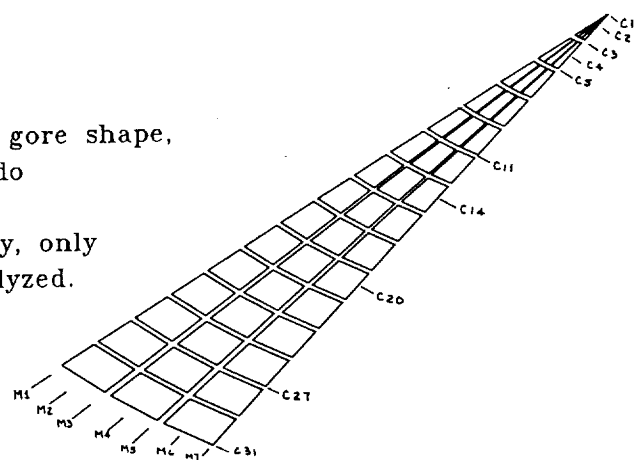
** Excessive Gun Debris - No Data

Improvements in Gore Design Tools

L'Garde has been using its FLATE computer code to determine the gore shapes for the paraboloidal dishes. Although this has sufficed in the past, a certain amount of adjustment was required during each test (pulling the outer mounting tighter, etc.). To cut down on the trial and error test time, a finite element code is needed. Thus, the gore design output from FLATE can be input to the Finite Element Code to predict the paraboloid's shape upon inflation. Several standard computer models have been tried with no success. The deformations upon inflation are simply too large for these routines to handle. This has led to the development of the LDIPS (Large Deformation of Inflatable Parabolic Shells) code. At present the code has been written, but verification (comparisons) to actual test data is needed.

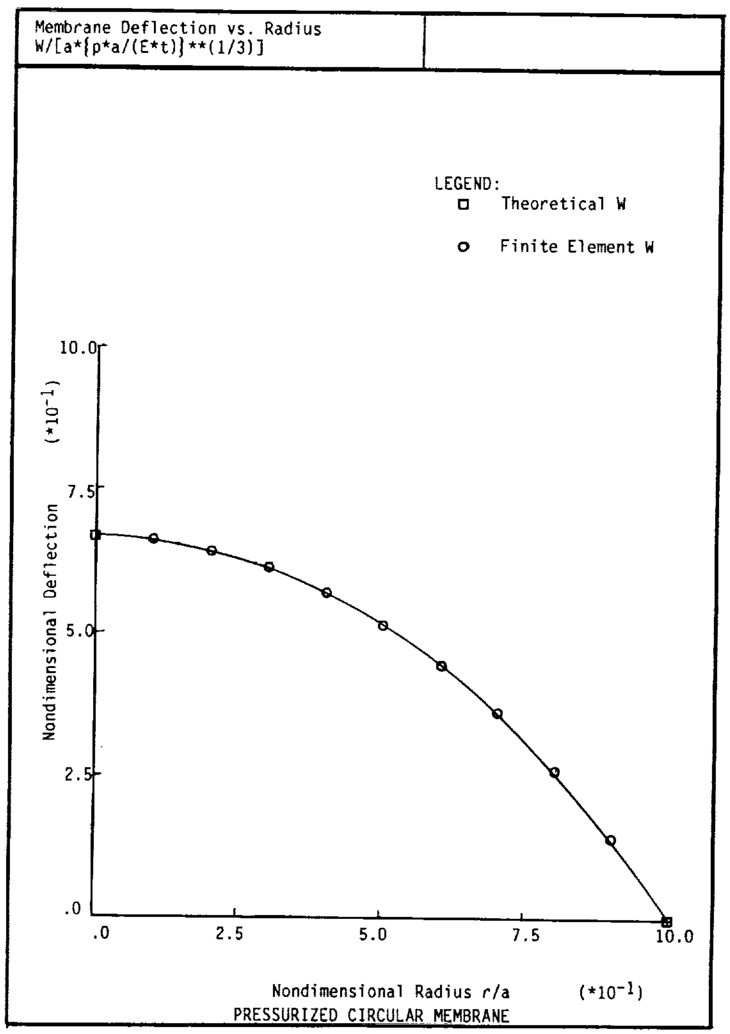
- Systematic Errors in Paraboloids
- Existing Finite Element Codes
  - ANSYS
  - ABACUS

  No Convergence
- Develop LDIPS Code
  - Given a specific gore shape, what will shell do upon inflation?
  - Due to symmetry, only one gore is analyzed.



LDIPS Data

The LDIPS code is a general purpose deformation analysis tool. So far, the code has converged only for the circular membrane case, where the membrane is made of straight-edged triangular gores. This will create a deformed dish which is not paraboloidal, but nonetheless serves to verify the code. Shown below, the results from the finite element code coincide on the graph with the theoretical closed-form solution. The next step is to input the curved-edge gore of the parabolic membrane into the code for verification. This problem is much more complex; preliminary runs have shown that the convergence time on the computer is at least twice that for the straight-edged gore circular membrane.



Expected Advances in Large Inflatable Antenna Technology in the Near Future

A variety of rigidization schemes have been used by investigators. Work currently going on at L'Garde will provide baseline data for all the concepts so that the most promising approach can be identified. Furthermore, for the precision reflector, we have identified the most promising approach for support structures and will be developing it. Attention is also turning at present to methods for protecting the various structures from the space environment (meteoroids, debris, oxygen-atom attack, space radiation, thermal effects) through coatings or multiple layers of film. The USAF plans to fly in space an inflatable concentrator soon to demonstrate the merging of these new technologies into a genuine system capability.