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SMART SPACE TECHNOLOGY

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Inflatable Space Structures - Redefining Aerospace Designe Concepts Keeps Costs from Ballooning

Mitchell Thomas

Inflatable space structures

Redefining aerospace design concepts keeps costs from ballooning

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We build large structures on Earth. To fight the pull of gravity, we have created steel-reinforced concrete columns, massive and strong. Our analytical tools and specialized designs are all based on this Earth-bound experience; and, over the years, we have gained an intuitive feel for how structures on Earth should be constructed.

As we venture into space, most of these tools, designs, and experiences hinder rather than help. To build or erect large structures in space, a new, expanded intuition is needed – an intuition based on inflatable structures that have only just been imagined in tbe last 20 or 30 years.

High payoffs exist for these structures. Indeed, unless such inflatable structures are developed, important scientific, engineering, or even cultural space projects will not be realized. (Earth-bound technology creates heavy, complex, cumbersome, unreliable, and extremely expensive structures making the projects too costly.)

Background

NASA recognizes the importance of inflatable structures. In the early days of the space program, NASA built a variety of inflatable satellites. These included passive communication satellites (Echo I and II), upper atmospheric density experiments (Explorer IX and XIX), and a Earth metric measurements satellite (PAGEOS - see Figure 1). These early satellites were developed in the NASA laboratories with the help of companies familiar with inflatable structures, such as Sheldahl and Goodyear.

The inflatables were chosen because the launch capabilities of early US (United States) vehicles were very limited. The space environment was still relatively unknown, so no one knew for sure how the inflatables would react to space. However, there were no alternatives. For these missions to be accomplished, inflatable structures were needed and they were used. Echo I, the first of these devices, achieved its mission, although apparently some sort of incomplete erection occurred. Since no onboard instrumentation could be carried on this early flight, it remains a mystery as to what happened. However Echo II, PAGEOS, and the Explorer satellites were completely successful.

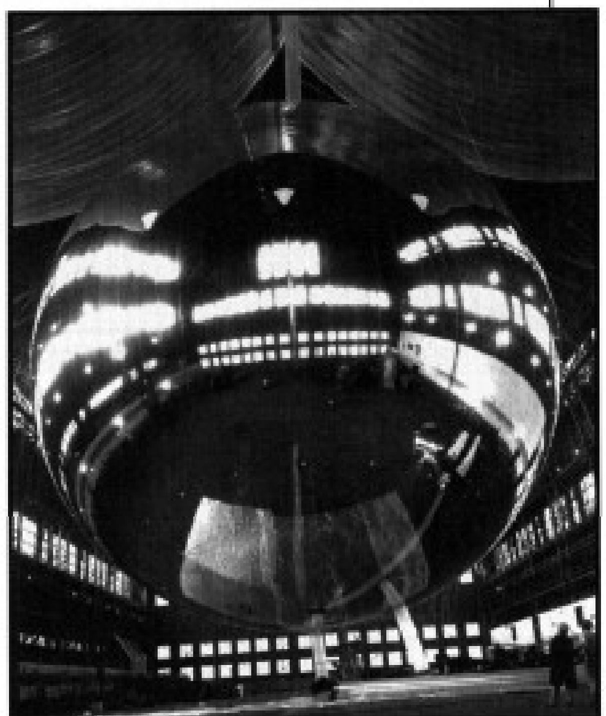

Fig. 1. Inflation test of *PAGEOS – a 100-ft* diameter satellite used in *the* National *Geodetic Satellite Program.*

Most of the early research on space inflatables centered on methods of making the structure rigid. There was much concern over keeping the structures erected by long-term inflation. The meteoroid flux in space was not well known, and estimates – in the Echo time frame – of the fluxes of meteoroids were too high by almost three orders of magnitude. Furthermore, the lack of analytical tools for the inflatables and lack of "Earth" experience with such seemingly flimsy structures reinforced the predisposition to build structures using established aerospace technology. The thought at that time was to make use of the inherent high deployment reliability of the inflatable, its ease of packaging, and low weight, but then to make the structure rigid.

Echo II and the Explorer satellites were rigidified by constructing their skin of a laminate of aluminum and plastic film. After the skin was pressurized and the wrinkles removed, the resulting aluminum shell structure was sufficient to carry any space loads.

In the seventies, work was done on space inflatables to support the US Air Force and Ballistic Missile Defense activities, constructing and flying inflatable decoy and target systems in space. Inflatables won out because of their inherent lower weight, lower packaging volume, ruggedness (ability to withstand nuclear blasts), reliability, and ease in making curved surfaces. Space rigidified inflatables were not of great interest in these projects, because the lifetime in orbit of any of these systems was only a few hours.

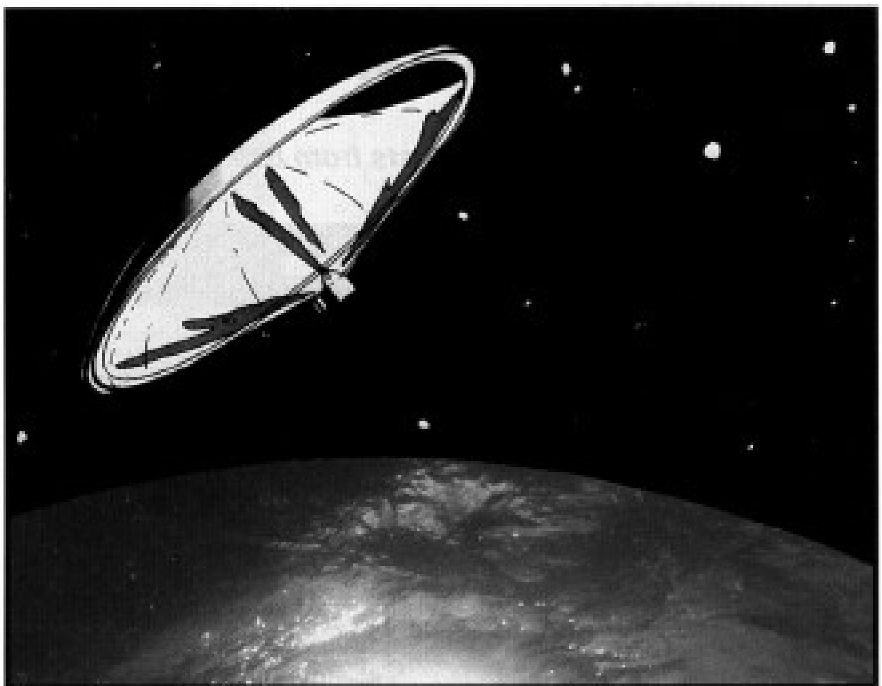

Fig. 2. Artist's *conception of a fully-inflated large space antenna.*

To support the NASA Advisory committee on Space Astronomy, the corporation, L'Garde, took a new look at the application of this technology to large space structures in the late 1970s. A surprising result was that fully inflatable antenna structures (Figure 2) could be built that would remain inflated in orbit for ten years. The meteoroid flux was now known to be much less than earlier estimates, and the large structures required very little pressure to maintain shape.

Ground tests had shown that the wrinkles in inflated surfaces could be removed if the stress in the skin exceeded about 300 psi. For a typical large inflated antenna, with a diameter of 14 meters or so, the minimum skin stress is 1000 psi using off-the-shelf 0.25mil-thick Mylar film if the inflation pressure is about 0.0001 atm! Such low inflation pressures, combined with the low meteoroid flux, meant that inflatable structures could be maintained by carrying along reserve gas to supply what leaked from holes in the skin. The weight of the inflatable structure, including its reserve gas and inflation system, then became less than many competing conventional space structures.

Figure 3 shows a comparison of data compiled by JPL with those calculated for an inflatable antenna. Over most of the size range, the inflatable antenna is lighter even though at the larger sizes it is being compared with rather diffuse net antennas. The comparison of packaged volume is even more striking (Figure 4). This result is significant because most flights on the Space Shuttle are volume limited rather than weight limited.

Technical issues

Inflatable structures can be used in many different applications and, therefore, take many forms. The Atlas missile, itself, was actually inflated by the fuel it carried, without which the missile would have collapsed. Space suits are a form of inflated space structure. Inflated man-locks were designed for Sky Lab.

The most challenging and exciting form are large precision structures.

Environment. In low Earth orbit, inflatable structures encounter attack by oxygen atoms. Some coatings appear promising' to slow down the attack. Since the large structures are mainly composed of hydrocarbon films, coatings (such as silicon oxide) are needed to protect them.

Along with the O-atom attack, at low altitudes, the lightweight inflatable may experience significant aerodynamic drag. This creates the need for a reboost, resulting in increased weight/cost. Therefore, the large inflatable structures will most likely spend most of their lives at altitudes above 300 nmi to limit both O-atom attack and drag.

When exposed for long times to high energy particles and intense UV radiation, the hydrocarbon films may degrade. Mylar becomes brittle and opaque. On the other hand, the polyimides (such as Kapton) have been used on long space missions with great success. Most of the gold super insulation apparent in photos of US spacecraft is constructed of polyimide film. NASA Langley investigators have developed a clear polyimide which should be useful in space applications; but, it is not commercially available.

The meteoroid and space debris effect on inflatables already has been stated. The approach is to allow the structure to be perforated and supply makeup gas. Tests run in a light gas gun to obtain simulated meteoroid impact against thin films have shown

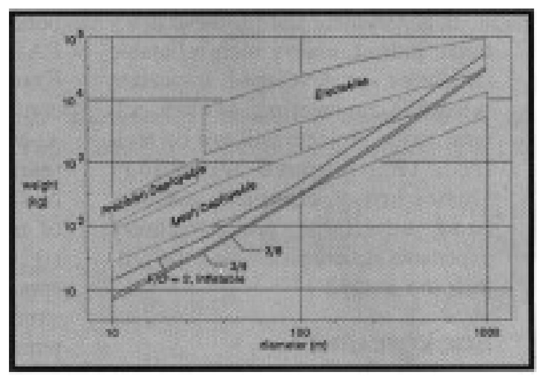

Fig. 3. ***Inflatables are generally lower in weight than industry projections of weight of conventional structures.***

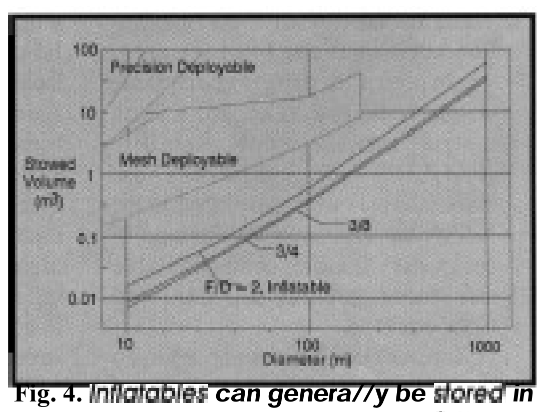

Fig. 4. ***Inflatables can genera//y be stored in volumes several orders of magnitude less than needed by competing structures.***

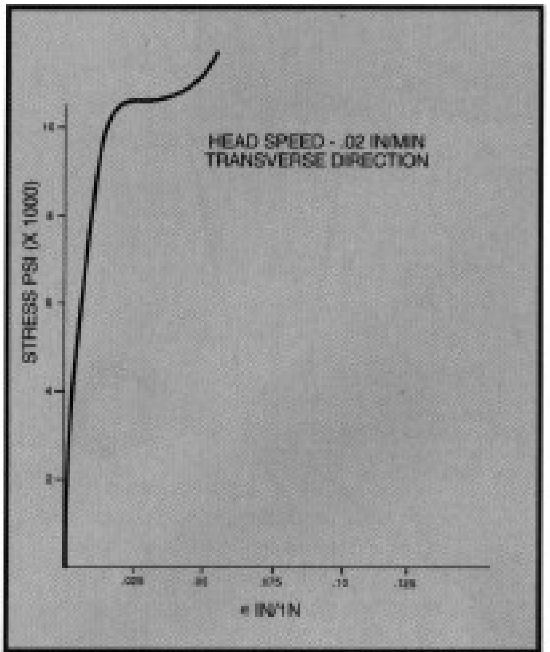

Fig. 5. A *typical stress vs. strain curve for Mylar, illustrating the large modulus (slope) variations.*

that multiple layers may be needed. The inflatable's outer surface acts like a bumper which shatters the meteoroid. For conventional structures these smaller fragments cause few problems. For the thin film inflatables, the impact tests showed that the effect of this shattering was to magnify the damage on the next surface hit. For protection from this effect, an intermediate thin film may be needed to catch and absorb most of these shattered fragments.

Surface accuracy. For a variety of applications, the inflatable space structure must maintain a surface of high precision. Such applications include solar concentrators and microwave antennas. The inflatable film's surface is made very smooth by inflation, but getting it to conform to a desired parabolic shape also may be needed. This can be done with the inflatable antenna by: accurate design of the flat elements the reflector is to be made from, accurate construction, and accurate control of the inflation pressure.

Accurate design requires good knowledge of the important parameters of the film used, such as thickness, elastic modulus, and Poisson's ratio. These parameters drive the accuracy of the structure. For example, the elastic modulus of typical materials is anything but linear (see Figure 5).

Figure 6 shows a typical inflated reflector made for ground testing. This surface was found to be parabolic to within 1 mm rms surface error over its 3 m diameter. Early studies looked at a variety of methods for making such large accurate inflatable reflectors, including forming sheets into paraboloids by hot molds, laser welding. However, the method that appears most useful is constructing reflectors out of flat gore segments (pie shaped) with tape over the butt joints. More complex methods do not appear promising for improving overall surface accuracy.

Analysis. Most standard analytical tools for structures do not work well on inflatables. Some reasons postulated are that the tools do not handle very large deflections well, or that the extremely thin sheets with strong resistance to motion in two dimensions, but hardly any resistance in the direction normal to the surface, is not easily handled by conventional finite element method (FEM) codes. Simple cases can be handled analytically, but to analyze any real system with high accuracy requires a good numerical procedure.

L'Garde, with the University of California (Irvine), has developed the first computer code that shows promise for these applications. Called LDIPS for Large Deployable Inflatable Parabolic Structures, this code works for more than just paraboloids, although it has been mainly used to analyze them. When comparing successive inflation steady-state contours for a massively-strained thin film, the finite element code results agree closely to the analytic prediction. This code has for the first time allowed the accurate prediction of the effect of the bonding tapes at the seams on surface accuracy.

Standard FEM codes can be used cautiously for inflatables for certain purposes, but they cannot accurately predict surface contours. This inability to use standard aerospace. tools for designing inflatable structures has added resistance to the widespread use of inflatables; but their day is coming!

Electrical properties. For a microwave reflector, the thin film structures are metaled. with a thin layer of a conductor. The ability of this film to reflect incident voltages depends upon the DC conductivity of the resulting metaled layer. Very thin layers of metal, usually measured in thousands of Angstroms, will provide almost total reflection from metaled, virgin films. However, after handling the films during manufacturing and packaging, the conductivity of the metal layer degrades and, in some cases, disappears. Examination of such films with electron microscopes has shown a multitude of micro cracks in the metal layer. Some materials are affected more than others. For instance, aluminum layers are strongly affected by these cracks while gold is not. We think that the aluminum cracks oxidize causing increased resistance.

A typical large inflatable system

Earth observations at microwave frequencies require large precision antennas. Figure 7 shows how an inflat-

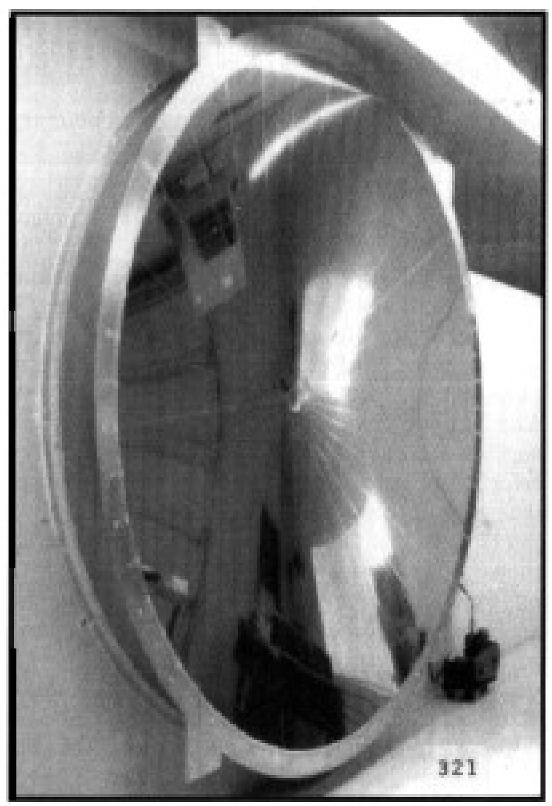

Fig.** 6 **Ground testing of 3-meter diameter inflatable paraboloid.

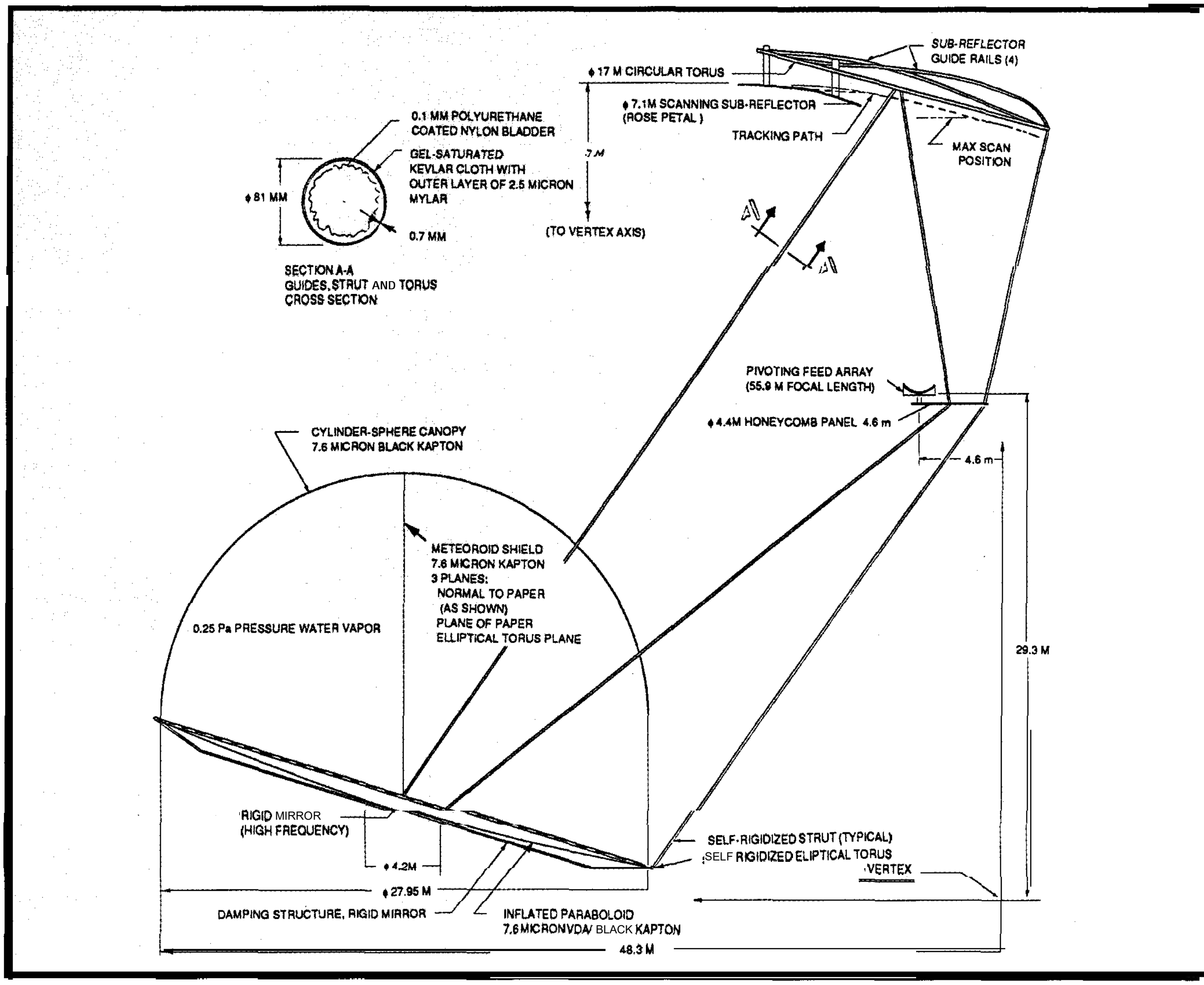

Fig. 7. Application of a large inflatable reflector for an Earth Sciences Geostationary Platform.

able structure can be used to make feasible an otherwise very expensive and probably not affordable mission. For high resolution imaging of the earth, the diffraction limit of the antenna drives up the antenna size to be very large and very accurate. For cm wavelengths up to frequencies of 8 GHz, a surface accuracy of about 1 mm rms error is needed in order to accommodate high-resolution imaging. Larger errors mean that the image will be corrupted from the sidelobes of the antenna. For the diffraction limiting case, antennas on the order of 50 m in diameter are needed to obtain the desired high resolution. At higher frequencies, the size requirement is reduced but the accuracy requirement becomes more severe, as the rms surface error allowed is directly proportional to the wavelength of the sensor.

The system in Figure 7 incorporates a highly accurate conventional antenna for the high frequencies, and a large inflatable antenna for the low frequencies. The small conventional antenna and the large inflatable antenna are both manageable with today's technology. And, they result in a workable versatile observation platform that would not be possible using only conventional aerospace technology.

Read more about it

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About the author

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