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Inflatable Structures Technology Applications and Requirements

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INFLATABLE STRUCTURES TECHNOLOGY APPLICATIONS AND REQUIREMENTS

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Abstract

There are a number of potential applications for space deployable structures. The users of such structures include the science, commercial and DOD community. Their stringent application criteria dictate the need for low cost, light weight and mechanically reliable space structures. Fortunately, a relatively new class of precision deployables has emerged that has tremendous potential for accommodating these demanding user application criteria. They are called inflatably deployable space structures and they are under development by organizations that include but are not limited to L'Garde, Contraves, Aerospace Recovery Systems, SRS, ILC Dover, Thiokol, and others.

As a consequence of the potential of this new class of space structures, a number of new functional system concepts have been conceived to exploit such capability. They include Space VLBI, LightSAR, Power Antenna, and Interferometer support structures. Space-based VLBI requires the use of one or more large size reflector antennas on orbit, viewing celestial radio sources, in conjunction with one or more large size ground based antennas. Synthetic aperture radar techniques frequently use large area deployable structures for the mounting of a large number of active radiating feed elements. The Power Antenna Concept is based on using a single large reflector antenna for both communications and solar energy collection for outer-planet missions. Unfilled aperture approaches for space based interferometry generally utilize large size structures for the mounting of a number of small telescopes for simultaneously viewing of astronomical objects.

This paper describes a number of specific potential missions for which inflatable structures might be enabling and how stringent user requirements led to the specific objectives used for the NASA sponsored IN-STEP Inflatable Antenna Experiment.

Introduction

Currently, no meaningful orbital assembly of space structures is planned for the space station. Consequently, some small and medium, and all large space structures will have to be self-deployable. The types of deployable space structures needed to accommodate a number of the new mission concepts include (a) booms, (b) solar-array support structures, (c) sun-shade support structures, (d) planar-array antennas, (e) solar concentrators, and (f) reflector antennas. However, because of limited resources at this time, the potential users of space-deployable structures technology are bound by stringent criteria for concept selection. The most significant concern to users is cost. Most of the large, conventional, mechanical-deployable structures are prohibitively expensive. Other user acceptance criteria include deployment reliability, mechanical-packaging efficiency, geometric precision, thermal stability, and long-term dimensional stability. In addition to these stringent requirements, the validation of new and promising concepts will have to include realistic demonstrations of concept performance, maturity, and low cost.

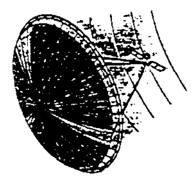
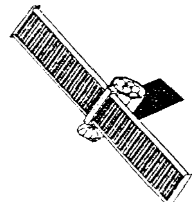
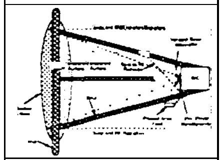
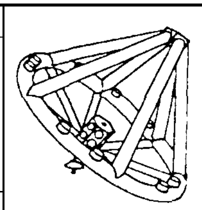
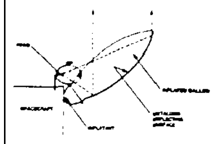
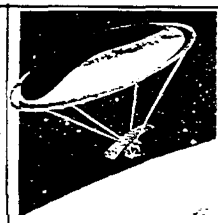
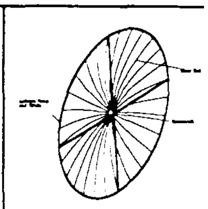
Fortunately, a relatively new class of deployable space structures has recently emerged with tremendous potential for accommodating the current user criteria. Even though inflatable space structures have been around for over 40 years, only recently have a very few organizations learned how to design and manufacture thin membrane structures with enough geometric precision to be seriously considered for specific classes of application. Organizations which have recently demonstrated a technology capability for large, inflatable space structures include L'Garde, Inc., Contraves, SRS, Aerospace Recovery Systems, ILC Dover, and Thiokol.

The specific technological capabilities, the objectives, and focus of the development and maturity of these inflatable concepts can be found in References 1 through 32.

Potential Inflatable Structures Applications

As a consequence of the potential capability of inflatable deployable space structures for numerous classes of application, a number of functional system concepts have been developed around specific inflatables concepts. A number of these system concepts and their inflatable structures technology needs are summarized in Table 1. Many of these system concepts are not just enhanced, but are fundamentally enabled by inflatables technologies.

Table 1. Inflatables Applications Summary

Mission	RF Interferometry	SAR Mapping	Outer planet exploration	IR/Optical Interferometry	High-data Rate RF Communications for Small Spacecraft	Earth Radiometry	Solar Observation of Planets
							
Application	Large Aperture RF Antennas	Large Planar Array Support Structure	Power Antenna	Interferometer support structures	Small Aperture RF System	Large Aperture RF Antenna (30 meter class)	Solar Sail support structure
Concept	10-30 m diameter, high-precision inflatable reflectors	5-25 m rigidizable structure	5-meter+ inflatable reflector for both RF communications and solar power concentrator	Accurate, 50-100 meter class inflatable rigidizable structure	1-3 m diameter inflatable reflector, conventional feed, mass less than 3kg, volume less than .01 m^3	10-30 m diameter, moderate precision inflatable reflector	150-250 meter diameter inflatable., rigidizable torus
Technical challenges	• long life; resistance to micrometeoroids • precision rigidizable support structures • low temperature rigidization	• atomic oxygen resistance (LEO applications) • support structure precision/planarity • flexible SAR array and integration with support structure	• long-term stability; • low temperature survivability • lifetime (leakage, materials)	• distributed inflation • controlled, assisted deployment • slow/controlled rigidization • dimensionally precise and stable structure	• lifetime (leakage, materials) • atomic oxygen resistance (LEO applications) • lightweight inflation system	• atomic oxygen resistance • low-emissivity materials and coatings	• distributed inflation • controlled, assisted deployment • slow/controlled rigidization
Application maturity/ development risk	Low-Moderate risk	Moderate risk	Moderate risk	High Risk	Low risk	Low-Moderate risk	High Risk

in [his paper, a number of these system concepts are described, along with the potential benefits of inflatables technologies to each. The specific inflatables technology development needs of each are also discussed.

The system concepts described below are:

- Tbc ARISE Mission: Orbiting Very Long Baseline Interferometry
- LightSAR: a concept for earth SAR topography
- The Power Antenna: solar power and high data-rate communications for missions to the outer solar system
- Interferometer Support Structure

The ARISE Mission: Orbiting Verv Long Baseline Interferometrv

ARISE (Advanced Radio Interferometry between Space and Earth) is a concept for utilizing orbiting antennas in conjunction with ground antennas to synthesize a highly sensitive RF interferometer with an effective baseline larger than the Earth's diameter.[33] It utilizes an orbiting, 30-meter class reflector antenna operating at 22 to 43 Ghz, working in conjunction with ground-based antennas to achieve high angular resolution of distant RF astronomical sources.

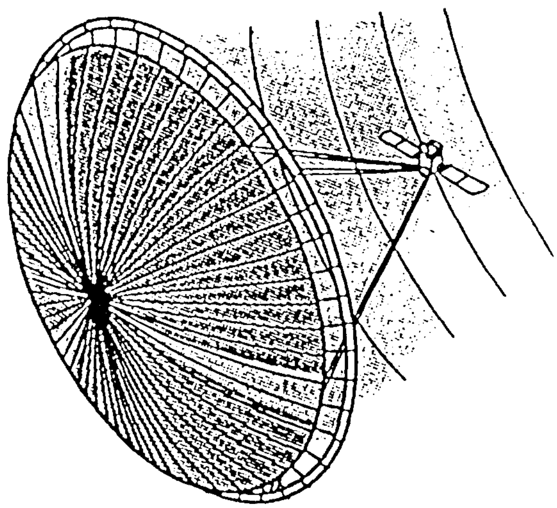


Figure 1. The ARISE Mission Concept

A conventional, mechanically deployable reflector structure of that size rrnd precision might be expected to cost hundreds of millions of dollars, weigh many hundreds of kilograms (depending on the technology employed), and have stowed dimensions which, driven by the deployment kinematics, may be constrained to be a significant fraction of the deployed size (i .e., up to several meters in length). The large mass and stowed volume of candidate mechanical deployable reflectors for this application would also necessitate the use of a large launch vehicle. In addition, the mass and inertia of such a large reflector structure would drive other elements of the spacecraft system design (such as attitude control system) resulting in increased mass and power consumption across the board.

L>c.pending on the lifetime required, and on the orbital environment in which it must operate, an inflatable deploy able reflector for this application might have an initial mass on the order of 100 kg, cost only a few tens of millions of dollars, and fit into a stowed volume of less than one cubic meter. The substantially smaller mass and stowed volume of the inflatable reflector might enable the use of a launch vehicle in the Atlas- or Delta-class, instead of the Titan-class vehicle which might be required to loft a system employing an equivalent size mechanical deployable reflector. In a fiscal environment where end-to-end mission costs, including launch vehicle, may be constrained to a few hundreds of millions of dollars, the use of inflatables technology for this application becomes enabling.

Technology developments needed for this application include improvements in the initial deployed precision of the inflatable, rigidizable support structures (torus and struts), continued improvement in as-manufactured of reflector surface accuracy, and enhanced long-term survivability of the thin-film materials. Note that all of these technology needs represent incremental improvements over currently existing capabilities — no major new developments are needed.

LightSAR: A Concept for Earth Global Topography

Conventional, mechanically depl oyable arrays for Synthetic Aperture Radar (SAR) observations require kinematically complex (hence, risky) deployment, and large rigid panels for support of the active array elements and [heir associated electronics and feed systems. The large stowed dimensions and high mass of these arrays also lead to a requirement for large, high lift-capacity launch vehicles.

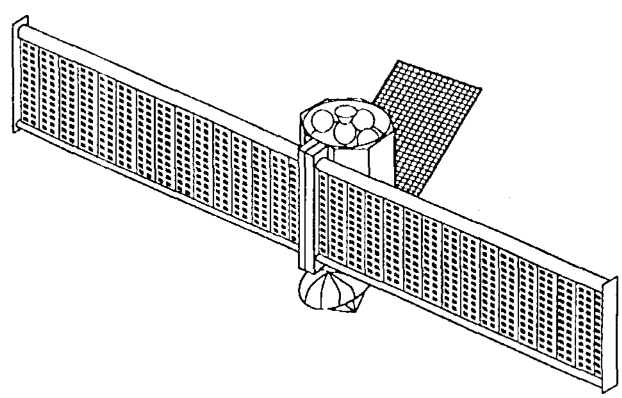


Figure 2. The LightSAR Concept

A new concept for a low-cost, lightweight SAR system has been developed based on inflatable deployable structures technology. The concept is called LightSAR (see Figure 2).[34]

It utilizes simple straight inflatable tubes supporting a flexible SAR array and groundplane, which can be compactly folded for launch. The inflatable deployed tubes and stowed cannister arc based on existing inflatable deployed solar array support structures developed at L'Garde, Inc.[35] The total mass of a 3 meter x 10 meter inflatable deployed array capable of operation at L-band (1.5 GHz) is expected to be less than 30 kg, including the tubes, canisters, flexible array blankets, and inflation system. If successfully developed, (his concept is expected to demonstrate major mass and cost reductions as compared to mechanical deployable designs. Together with other ncw technologies for the reduction of spacecraft mass and volume, it is anticipated that a SAR mission employing inflatable support structure technology could bc launched on a Taurus-class launch vehicle, while the comparable system based on conventional mechanical deployable structures technologies would require a Delta II.

Inflatables technology developments needed for the support structure for this application include improved precision inflatable, rigidizable structures (particularly for higher frequency applications), improved atomic oxygen and ultraviolet resistant thin film materials, and lightweight inflation system development. Again, all of these represent incremental improvements to existing technology. A companion and application-unique technology development needed is a lightweight, flexible radiating element support structure (SAR array) which can bc compactly stowed with the inflatable support structure.

Tbc Power Antenna: Solar Power and High Data-rate Communications for Missions to the Outer Solar System

The Power Antenna (sec Figure 3) is a concept for combining the functions of solar concentrator and RF communications antenna into a single aperture. 'l'his concept has the potential to enable all-solar missions to the outer planets, while simultaneously increasing data return rates by 1-2 orders of magnitude. Increased downlink data rates would also have the effect of reducing mission operations costs by reducing DSN usage requirements.

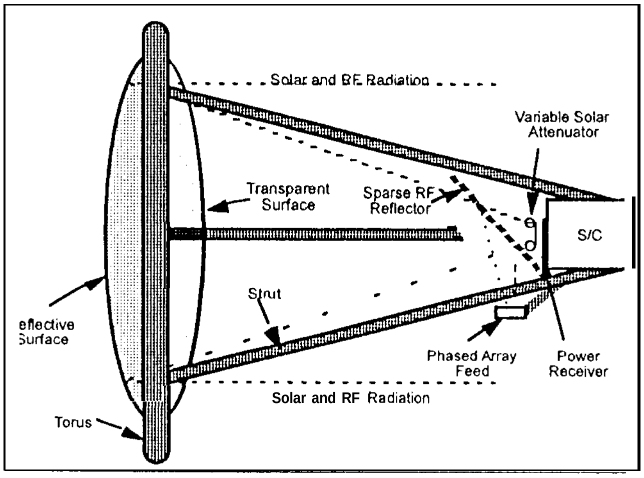


Figure 3. The Power Antenna Concept

The apertures required to provide spacecraft power via solar concentration at the outer planets can bc quite large: anywhere from approximately 8 meters up to 30 or 40 meters in diameter. In order to perform the function of solar concentrator, the reflector surface mus(bc continuous — a mesh deployable would not suffice. If inflatable apertures arc not available, it would be necessary to utilize heavier, more expensive, mechanically deployed solid-element reflectors to perform this function. The mass and cost of such mechanical reflectors in this size range is estimated to bc one to two orders-of-magnitude higher than the inflatable design. If the cost of tile mechanical alternative itself were not prohibitive, the cost of a launch vehicle capable of lifting such a large and massive system might bc. As a consequence, inflatable reflectors are considered to represent a fundamentally enabling technology for this concept.

Detailed technology development needs for the Power Antenna concept arc contained in Reference 36. The principal elements are summarized here.

1. Large, lightweight inflatable apertures (5-40 meter class) which can perform both as RF communications antennas and as solar concentrators
   smooth, highly stressed reflector membranes
   - high-reflectivity coatings
   - low-loss (highly transparent) canopy materials
2. Precision, low-temperature rigidizable support structure
   low-temperature (phase-change) rigidizable materials
3. Compact, lightweight solar receiver (either photovoltaic or thermoelectric) in the 100 Watt class for conversion of the concentrated sunlight into electrical power
4. Phased-array RF feed for offset pointing of communications signal from reflector boresight
5. RF "beamsplitter" for separating RF signal from the collected solar energy
6. Variable solar attenuator (to accommodate concentrator/receiver operation at a wide range of solar distances)

Interferometer Support Structure

A number of concepts have recently been developed which utilize arrays of optical or IR telescopes for astrometric interferometry applications. For some of these systems, the individual small (1 -meter class) apertures must bc physically connected and aligned. As the dimensions of the required support structures arc in the range of up to 100-150 meters,

inflatables represent **a promising alternative to expensive and heavy mechanical deployable truss-type structures. The Switzerland-based company** Contraves **has proposed the** usc **of** an **inflated,** rigidized ring, 20 meters in diameter, to support twelve 1.2-m **apertures** for the SISTERS (Space Interferometer for the Search for Terrestrial Exo-planets by Rotation Shearing) interferometer.~' A number of other interferometer concepts have recently been developed at the Jet Propulsion Laboratory which could utilize inflatable support structures up to 100 meters in size.

The major challenge for the application of inflatable structures to this class of instrument is for the inflatable to achieve sufficiently high initial deployed precision and predictability. Secondary challenges are to maintain adequate dimensional stability and stiffness over the mission duration.

User Validation Criteria for New Concepts

Strong user interest in the application of inflatable space structures has contributed to a number of technology developments of inflatable structures concepts. However, prior to actual usc of this new type of structure, a number of realistic demonstrations and validations will bc essential. They include (a) demonstration of low cost and weight by actually building large flight-type hardware, (b) demonstration of high mechanical-packaging efficiency by actually stowing a large flight-type structure in a small container, (c) demonstration and validation of deployment reliability with large flight-type hardware in a realistic zero-gravity environment, (d) demonstration of initial surface precision and thermal stability in a realistic thermal environment, and (e) ground-based demonstrations that arc appropriate for some types of performance validations.

IN-STEP Inflatable Antenna Experiement

The NASA-sponsored IN-STEP Inflatable Antenna Experiment (IAE) is intended to address the concerns of the user community and reduce the risk of applying new technology by validating a large inflatable-deploy ablcantcnnastructurc on orbit on S'1'S 77 in May of 1996.

The objectives of the experiment arc intended to specifically address the antenna user-application criteria. Consequently, the specific objectives are to (a) validate the deployment of a 14-meter diameter, inflatable-deployable, offset parabolic reflector antenna structure in a zero-gravity environment, (b) measure the reflector surface precision, which is expected to be on the order of 1 -mm rms, for several different sun angles and inflation pressures in a realistic thermal environment, and (c) demonstrate that a large flight-quality structure can be built at low cost and that it can be stowed in a very smrrll-size container, Details of the experiment arc given by References 38 through 41.

While the IAE will be a major step in the validation of inflatable deployed structures technology for precision applications, a great deal more work still needs to be done to fully realize the tremendous potential of this technology.

Conclusion

Limitations of government resources for science, industrial investment capital, and future DOD budgets have resulted in a "search" for a better and cheaper way to develop, validate, and actually use large deployable space structures, Inflatables structures have been identified as the "best" new and innovative concepts at this time. As affordable, low-risk new technologies emerge and are validated, so will new and innovative functional system concepts that exploit the potential capability.

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