INFLATABLES FOR LIGHTWEIGHT SATELLITE APPLICATION

GEOFFREY WILLIAMS

L'Garde, Inc.
15181 Woodlawn Ave.
Tustin, CA 92680
(714) 259-0771

ABSTRACT

In the 1960's, NASA put considerable effort into inflatable space structures, including Echo I and II, PAGEOS and Explorer IX and XIX. Overall, inflatables in space have been successful and their inherent advantages have been demonstrated. Inflatable space systems invariably require less packaged volume, are lower in weight and cheaper through both development and production phases than competing mechanically erected systems. The meteoroid problem is much less than originally anticipated because large antennas and reflectors require very low inflation pressures; gas lost through leaks can be replaced from a small supply of reserve gas. Inflatable apply themselves extremely well in space, where the absence of gravity creates extremely low design loads.

Several applications of inflatables are outlined, including: solar concentrators for solar thermal propulsion and space power systems, communication antennas, and radiators for heat rejection in space.

Inflatable make sense in this era of limited booster capabilities and are especially applicable to lightweight satellite systems. They make possible important missions that would otherwise be far too heavy and costly.
INTRODUCTION

Inflatable systems that are shaped and maintained by gas pressure offer many significant advantages over other competing space structures.

a. They are low in weight and package volume.

b. They have low launch costs due to their extremely high packaging density; this last factor can dominate the total mission cost, making the use of inflatables mandatory for many applications that otherwise could not afford to be done.

c. Typically, inflatables have a low cost for development and production.

d. Large inflatable structures are self-deployable, requiring no astronaut intervention.

e. Gas pressure attempts to perfect bodies of revolution, enhancing accuracy.

f. Inflatable are not susceptible to launch vibrations and acoustics, and have excellent on-orbit dynamics. The inflatant provides a means of damping the thin structure.

g. Precision structures can be fabricated and tested on the ground, using a bouyant inflatant, as a means of floating the structure.

SOLAR CONCENTRATORS

Solar Thermal Propulsion

L'Garde is developing reflectors for use on the solar rocket (See Fig. 1). Future applications in space require transporting heavy payloads from low earth orbit to geosynchronous orbit. Current chemical propulsion is a costly, inefficient method of performing this task; solar thermal propulsion nearly doubles its efficiency in terms of specific impulse (Isp). A solar propulsion system has large collectors that gather the sun's energy, reflect and concentrate it into a chamber in which a gas is heated to a very high temperature. This extremely hot gas is then expelled through a standard nozzle to produce a thrust. The concentration ratio required to create these high propellant temperatures (5,000°R) is approximately 10,000; this means that the incident radiation upon the absorber surface is 10,000 times the intensity of normal solar radiation in space. The problem in the past with this concept has been
the large space deployable collectors. Their weight and packaging volume have been too great to make the solar rocket a viable concept. Large, highly accurate solar reflectors are required which have low weights and small packaging volumes. These requirements are best met by an inflatable system.

Under the Highly Accurate Inflatable Reflector (HAIR) program for the Air Force Astronautics Laboratory (AFAL), 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 RMS1. Several 1-meter reflectors were developed and tested during the program which verified this finding. 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 error2 (Fig. 2). Using the Concentrator Optical Performance Software (COPS), the concentration
ratios attainable on the solar rocket with this 3 milliradian slope error is 10,500, which will suffice for the high temperature propellant requirements. During this program, a system study of the solar rocket led to the present design of the reflector system. 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 off-axis reflectors, such as those used on the solar rocket, will be developed. Design and testing of a 2 x 3 meter test reflector is now in progress. Results of this testing will lead to the development of an upscaled 7x9 meter test reflector, along with the associated torus and truss elements. This will involve pointing accuracy and packaging/deployment tests to verify its usage for the solar rocket.

In parallel to the HAIR/DSCE ground testing programs, L'Garde has just completed a Phase I SBIR contract (F04611-86-C-0054) with AFAL leading to an in-space flight test of the reflector developed under DSCE. During Phase I, a preliminary design was generated for a meaningful flight test, as well as a program plan for the necessary detail design and development testing tasks that will lead to actual flight using the space shuttle's Get Away Special in 1991. The Phase II program will take the flight test hardware all the way through development testing.
Solar Dynamic Power Systems

Future military missions in space will require abundant power for use on satellites. Conventional photovoltaics have been used in the past and provide a reliable source of power; they do have several drawbacks however. Their low efficiencies make it necessary to use large areas of cells, requiring extendable hard structures for support. This large structure makes for a complex deployment scheme as well as a high system weight. As another drawback, the large area required for the low efficiency cells will create significant drag for satellites, especially in Low Earth Orbit (LEO). Solar Dynamic Power Systems (SDPS) offer a viable alternative to photovoltaics, with lower system weight and drag area. These power systems, typically consist of large parabolic reflectors that focus the sun’s rays onto an absorber where the high intensity heat is collected. In turn, this heat is used to mechanically generate power using a Brayton or Rankine cycle engine. The lower system weight and area is mainly due to the higher efficiency of dynamic power systems; for a given area of collector surface, more energy is generated with the dynamic power system than with photovoltaics.

Currently, L'Garde is involved with several contracts dealing with solar concentrators for use in space. Under contract with Martin Marietta, L'Garde is performing preliminary designs and planning ground tests leading to the development of a SDPS for satellite power. The baseline system consists of an off axis segment of a paraboloid dish with approximate dimensions of seven (7) by nine (9) meters (See Fig. 3). The concentration ratio required by this type of system is on the order of 2,000.

For long lifetime applications (> 5 years), L'Garde is studying various methods to rigidize the reflector. Such a system will inflate to its required dimensions, then self-rigidize so that the inflatant is no longer necessary to hold its shape. The several rigidizing methods currently being considered are:

a. The use of space curing resin impregnated in Kevlar fabric.
b. Pressurizing a thin aluminum sheet to its yield point, making it acquire a permanent set.
c. The use of polyurethane foam.

Each of these methods will be compared to the fully inflated configuration. The entire system weight for the inflated system, including all the necessary structural elements (truss and torus), inflation hardware, and the excess supply of gas to replace that lost
through meteoroid holes*, is 28 pounds, making a weight per reflector surface area ratio of .25 kg/meter². This is hard to beat, using any of the rigidizing methods above.

* An analysis of the meteoroid problem is given in Reference 5. Prior estimates in the 1960's of the meteoroid flux in space were grossly overestimated. Current data indicates that the holes produced from meteoroid penetration are small and the amount of gas lost can be replaced by a supply of make-up gas which is only a fraction of the system weight.
In regards to lightweight satellite application, one obvious need is lightweight antennas for communication purposes. One concept is shown in Fig. 4. The parabolic dish antennas are closely related to the solar concentrator, but differ in their requirements for surface accuracy. Radio antennas can tolerate a larger amount of surface inaccuracy due to the longer wavelengths involved. It is required that the size of the surface inaccuracies or bumps be smaller than the wavelengths reflected. This makes the surface requirements much less stringent for antennas than for solar reflectors.

Fig. 4 Pressurized Space Antenna Concept

Shown in Fig. 5 are the weight and packaging volume of pressurized antennas for several focal length to diameter (f/d) ratios. These are compared to other types of systems, as found during a NASA-sponsored contract. The data for inflatable systems includes the necessary structural components, the inflation hardware, and the replacement inflatant. Inflatables offer a definite advantage in the areas of weight and packaging volume. This is most important now in this era of limited launch vehicle assets.
Fig. 5  Antenna Weight and Package Volume vs. Size
An inflatable antenna module study was done for Martin Marietta (contract #19980) in 1980. L'Garde was required to design a large inflatable antenna system and components for use at centimeter wavelengths in space. Parametric designs were made for antenna systems from 15 to 30 meters in diameter, including sensitivities to pressure, thin film characteristics, interface, temperature and other environmental phenomena. A detailed model of the thermal performance was developed. Considerable effort was expended in defining the inflation system characteristics. A preliminary test plan was developed showing how these systems could be tested in a simulated zero-g environment by floating them using a helium inflatant. A detailed antenna analysis was made to determine the sidelobe patterns as they were altered by the systematic distortion resulting from the seamed construction. The effects on antenna performance were found to be negligible. Another contract with Martin Marietta (Contract #19954, 1980) required L'Garde to analyze and support Martin Marietta in the design and evaluations of a large inflatable spherical reflector antenna system (275M diameter, 1500 gores). A development plan for the system was a major program output.

RADIATORS

Under the Strategic Defense Initiative (SDI) program, a number of spaceborne weapons are being developed that will generate large amounts of power for a short period of time. They will sit nearly dormant in space until the day they are needed; then they may use considerable power, in the tens of megawatts. This waste heat must be rejected from the SDI satellite, or else the sensitive components will be destroyed by absorbing the energy, which will be on the same level or higher than that expended to kill one or more threat ICBM's. This unique feature of the SDI satellite leads to energy radiators that will not resemble ones used on current satellite systems, where the heat rejection is at a relatively low level or continuous.

To size a conventional radiator to handle the peak energy loads for such a SDI satellite would result in an unacceptable weight penalty. Weight is at a premium and an overweight system can result in launch costs that can drive the system out of feasibility. Several studies have looked at phase-changing coolants coupled with expandable radiators to solve this peak power problem. The radiator weight is greatly reduced by temporarily carrying the waste heat as the heat of vaporization of a coolant; the resulting vapor then drives open an inflatable structure which provides a large, but temporary, radiating surface to discard the stored heat. Fig. 6 shows the design currently being developed by L'Garde.

A radiator that can be kept packaged until needed has other distinct advantages in the SDI scenario. The large radiator areas required would create significant drag -- from the thin atmosphere at low orbits and, much less but still significant, from solar radiation pressure at high orbits. The resulting accelerations translate directly into weight of propellant for station keeping. Also, the satellite will be more
vulnerable to tracking and being attacked if a highly-observable large conventional radiator is attached. Furthermore, a system with a packaged radiator will be easier to harden to attack, especially to nuclear bursts in the vicinity. The packaged radiator will not suffer meteoroid punctures, which can also affect system weight by requiring extra coolant to make up losses, or extra shielding on the radiator. Thus, significant advantages result from using an expandable radiator; these advantages can make the difference between the satellite system being practical or impractical.10,11

OTHER APPLICATIONS OF INFLATABLES

In addition to the solar concentrators, antennas, and radiator discussed above, several other applications of inflatables have been developed by L'Garde.
Inflatable Structures:

The need for extendable booms and truss elements is inherent for many deployable structure satellites. The simplest method of deploying a truss structure is by simply inflating it, where the compressive force in the truss members is resisted by the inflatant gas pressure. This would suffice for many applications where the loads are in compression/tension only.

For members subject to significant bending, rigidization methods should be employed. As discussed earlier, these methods may include: pressure rigidized aluminum foil tubes, polyurethane foam filled tubes, and gelatin/cloth composite tubes. These concepts are presently being analyzed/tested by L'Garde for several programs, including DSCE.

Gravity Gradient Inflatable Booms

The differences in the earth's gravity field between the upper and lower end of a satellite can be used to generate a torque which aligns the long vehicle axis with the local vertical. This effect can be greatly enhanced by extending lightweight booms with small weights on the ends. Passively damped systems are favored for small satellites (less than 1000 lbs) and for low altitudes (below 1000 nautical miles) where the gravity gradient torque is still strong. An inflatable boom with a small mass on the end would offer the following advantages for a small satellite:

a. Simple packaging  
b. Lightweight  
c. Involves no active control elements  
d. Requires no attitude sensors  
e. High reliability

Aerodynamic Braking:

There are two problems with the proliferation of man-made space borne objects. First, the space arena around the earth is literally filled with space debris that represents a hazard to future space projects. The second is the hazards these objects represent, unless they burn up in the atmosphere, when they return to earth such as was the case of the Russian nuclear power plant which hit Canada and the U.S. Sky Lab which almost hit Australia. The space around earth is polluted and the North American Air Defense System daily tracks by radar over 6,000 baseball sized and larger space junk. 300 of these objects are operating satellites and there are another estimated 40,000 golfball sized objects which are not tracked. This debris includes expended rocket stages, rocket panels, fragments from satellites, nuts and bolts and even hand tools that the astronauts lost during their walks in space. This space junk is growing and something must be done to clean it up. This pollution primarily resulted because there was no controlled way to deorbit this debris except by natural gravitational pull and the object's
small drag area. The present system of relying on this method results in an uncertain and sometimes untimely reentrance of this debris in large populated areas or in unfriendly territory. The present prediction of reentry is very uncertain with NORAD only knowing when and where it went down when it fails to appear in a predicted orbit. If a simple device could be used to control the deorbiting so that it could make satellites etc., reenter in a safe and friendly area it could reduce both the hazards to populated areas and prevent unfriendlies from capturing our technology and secrets. An inflatable braking device(s) on a satellite or space station etc., could be a simple solution for this and has the following advantages:

a. Lightweight  
b. Simple packaging

The inflatable aerodynamic braking could take many forms but would be a large inflatable bag which would be designed to offer increased drag when it was needed. The inflatable could be designed so that after it served its purpose could be discarded upon reentry in the atmosphere. It also could be designed to act as an inflatable reentry heat shield to both control the deorbiting satellite and protect it during reentry, allowing its payload to be recovered or used again.

Decoys

L'Garde has also developed numerous decoys, targets, and replicas for use in Penetration Aids programs. Several advantages to inflatables are present here -- their lightweight and low packaging volumes, self-deployability, and most important, the ability to tailor specific radar signatures by strategic choice of the balloon materials and coatings. L'Garde developed decoys have flown successfully on sounding rocket flight tests from the Western Test Range to the Kwajelein Missile Range (KMR).

The use of inflatable decoys is particularly applicable to the Light-Sat program. Their vulnerability to attack can be greatly reduced by the dispersion of numerous decoys while the system is subject to attack, creating a cloud of objects with optical signatures the same as that of the operational satellite.

CONCLUSIONS

The need and importance of lightweight/packagable/self-deployable payloads for use in space cannot be over-emphasized. Limited booster assets, augmented by the Challenger incident, have backlogged deliverable payloads to a point where every way of reducing pounds and cubic feet must be considered. The demonstrated advantages of inflatables are indeed most applicable to light weight satellite systems, where the emphasis is on redundancy and small size.
REFERENCES


