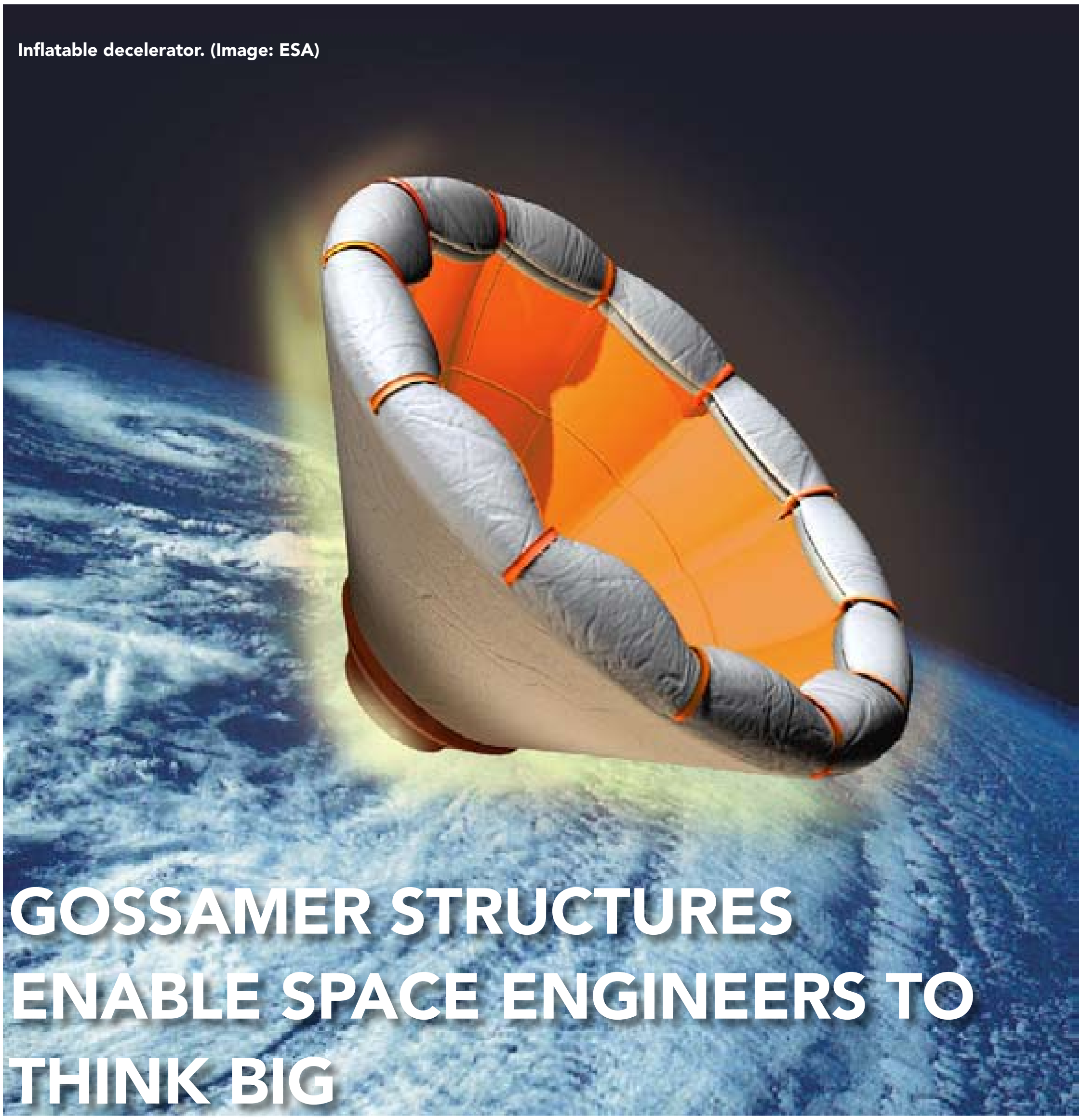


Inflatable decelerator. (Image: ESA)

GOSSAMER STRUCTURES ENABLE SPACE ENGINEERS TO THINK BIG

Gossamer space structures are a recent development in structures technology. Andrew Lennon, Chartered Engineer, describes how modern challenges are driving this area of structures engineering.

Gossamer is fine spider web that floats on the wind. It gives its name to a special class of structures known as gossamer structures. These structures resemble a spider web with their high flexibility and ultra-low-mass. Small stowed volume and ultra-low-mass are highly desirable characteristics for space applications.

Space launch vehicles (space rockets) have restricted dimensions in the payload bays and can carry limited payload mass to space. Gossamer structures technology allows engineers to devise large space structures that would be unfeasible with more traditional structures technology.

Characteristics of gossamer structures

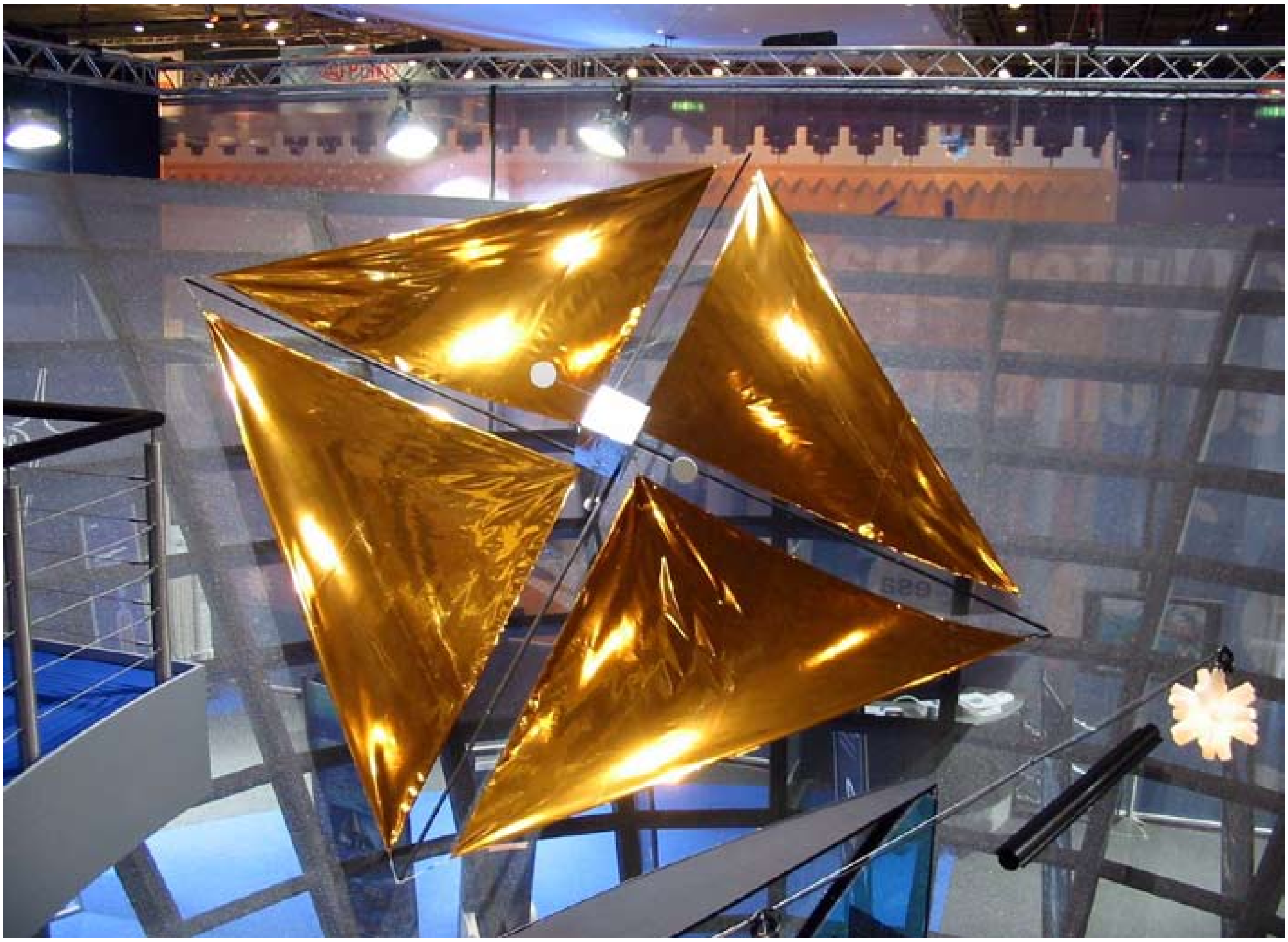
The Gossamer Structures Program Committee of the American Institute of Aeronautics and Astronautics (AIAA) define gossamer spacecraft as systems that have high deployed to packed volume ratios and are extremely low in mass.

A key characteristic of gossamer structures is the areal density, area divided by mass, and is usually expressed in grams per square metre (gm/m^2). Areal densities for membrane and gossamer structures in space tend to be very low, less than 10 gm/m^2 for some structures. Compare this figure to standard photocopy paper, which has a density of 80 gm/m^2.

Flexibility is another characteristic of gossamer structures. Gossamer structures typically use membranes as the main component. The structural definition of a membrane is a sheet of material that has negligible bending stiffness, hence the high flexibility of gossamer structures.

The lack of significant bending stiffness means that the membrane cannot support load via bending, nor can it support load via compression as it buckles and wrinkles at negligible load. Tension is the only load path that is available in a membrane.

Working with structures made from flexible membranes requires a change in mindset for engineers, who tend to be familiar with more conventional structures where bending and compression can be used to carry load. Developing intuition for the behaviour of membrane materials and gossamer structures is essential for successful design, construction and operation.



Solar Sail Model. (Image: ESA)

Membrane structures

Humans have used membrane structures for thousands of years, ever since people began using animal hides to form shelters. The inherent advantage of these early structures was the comparative lightness of the structure against the area covered by the shelter. The usefulness of modern membrane structures depends on the same characteristics.

Modern examples of engineered membrane structures are tents, sails, balloons, and parachutes. The unifying feature of all membrane structures is the thin membrane material in tension. The tensioned membrane is supported by poles or masts in the case of tents and sails, and by air pressure in the case of balloons and parachutes. Inflatable membrane structures are supported by the pressure of an internal gas.

Membrane structures technology for shelters has advanced considerably since the pre-historic shelters of animal hide. Membrane structures technology has advanced to the stage where membrane space structures can be used to build space habitats.

The two leading designs are TransHab by NASA and Genesis by Bigelow Aerospace. NASA discontinued TransHab at the design stage but the private-enterprise Genesis led to the launch of prototype spacecraft. Genesis I entered orbit in July 2006 and Genesis II followed in June 2007, providing practical experience with inflatable space habitats. Bigelow announced in February 2008 that it intends starting launches to its planned commercial space station around 2011.

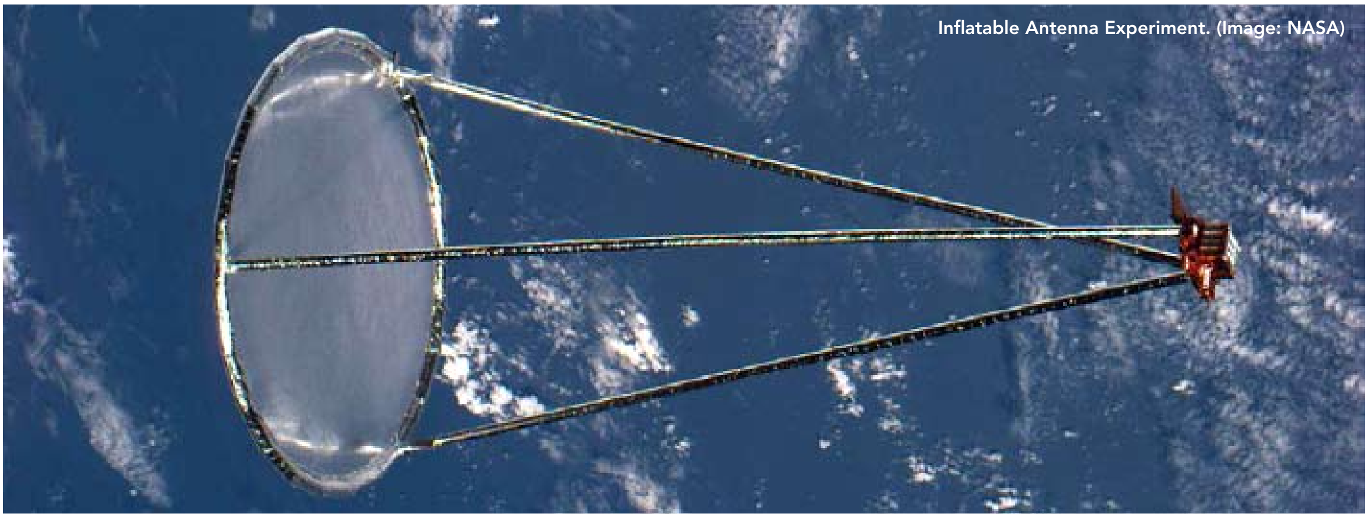
Gossamer structures in space

Membrane structures usually have low areal density but are not necessarily deployable. The additional requirements for deployment ability, and for a high ratio of deployed to stowed volume, separates gossamer structures from other membrane structures.

Examples of space structures that meet the stricter definition of gossamer structures are inflatable antennae, deployable membrane solar arrays, inflatable parachutes and decelerators, elements of inflatable space habitats and balloons deployed from spacecraft for space and planetary exploration.

Space is a harsh environment that poses many challenges, from design, through pre-launch processing, launch, deployment and finally to in-space operation.

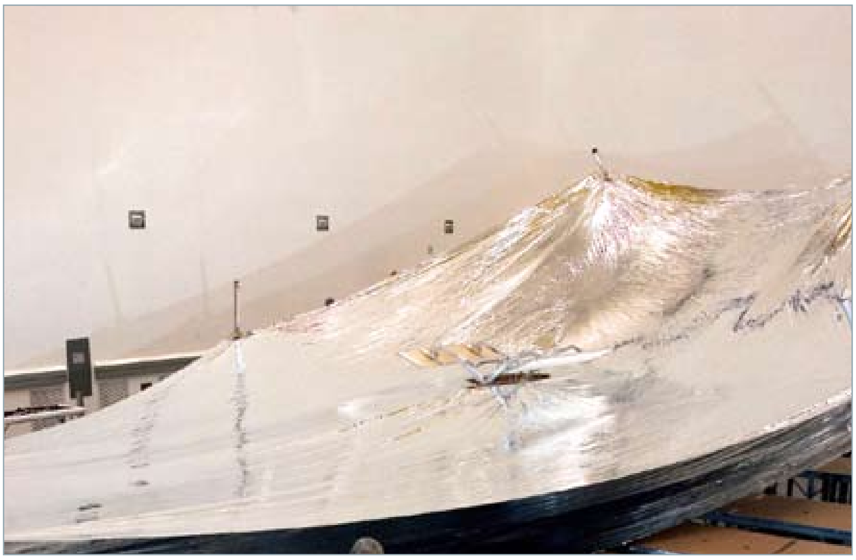
The gossamer space structure must fit in the payload space available on the launch vehicle, it must survive the accelerations and vibrations of launch, it must deploy properly, and it must survive the harsh environment of space. The near-vacuum environment requires the structure to operate without the comfort of the atmosphere. No atmosphere means no shielding from micro-meteorites, dust and debris; no ozone layer to reduce the harmful ultra-violet radiation from the sun; no thermal insulation, bringing exposure to the frigid cold of space or the scorching heat of the sun. The designer of gossamer space structures must be careful to address the challenges of the space environment but without adding material to the structure that would negate the ultra-low-mass advantage of gossamer structures.


Inflatable Antenna Experiment. (Image: NASA)

Balloons for space exploration are amongst the earliest spacecraft and appeared at the start of the space-age. The Echo satellite was a balloon launched into space in 1960 and used as a reflector to test transmission of intercontinental signals. Its technological descendent is the Inflatable Antenna Experiment (IAE), launched on space shuttle Endeavour in 1996. The IAE is an example of an inflatable space structure, with an inflatable reflector, inflatable supporting rim and three inflatable members supporting the transmission equipment. The IAE provided essential experience with inflation in space and provided valuable data for the design of future structures. Current plans call for gossamer structures technology to be used in advanced spacecraft such as the James Webb Space Telescope (JWST). The JWST is the planned successor to the Hubble Space Telescope, and current schedules call for launch in 2013 or later.

Far from Earth

The JWST will incorporate a deployable sunshield using layers of membrane material. The use of gossamer structures technology for the JWST shows confidence in this field of technology, as the telescope will be used at a location far from Earth where servicing and access are impossible.
Inflatable masts, habitats, inflatable antennae, decelerators,



Testing the sunshield for the James Webb Space Telescope. (Image: NASA)

TransHab inflatable habitat design (Image: NASA)

and space sails are some of the ideas being developed by space agencies and industry around the world. Inflatable masts are attractive because of their small stowed volume compared to the deployed length. Human exploration of planets or the moon will require habitats if the presence is to be longer than a few days.

The astronauts will require a large volume of space for living and working, and this requirement means that the structure must be able to pack into a significantly smaller space for transportation from Earth to the lunar or planetary surface. Habitats using inflatable structures are a solution to this requirement. ESA intends to issue tenders for components of both inflatable masts and inflatable habitats.

Other ideas include inflatable solar concentrators, telescope collectors and antennae. These concepts rely on the development of large-diameter inflatable lens/reflectors. Developing an inflatable lens/reflector is a significant challenge for gossamer structures technology as the structure must be free of wrinkles, adopt the desired parabolic curved shape, and maintain its shape without significant distortion in the space environment.

Returning cargo from space is difficult but a desirable feature for scientific payloads. One idea is to use an inflatable decelerator to re-enter the atmosphere. The inflatable decelerator is a specially shaped structure, designed to slow the cargo as it falls to earth but without incurring the high cost of other spacecraft.

Space sailing

Space sailing is an elegant concept and represents an interesting but challenging application for gossamer structures technology. Solar sails use the pressure of sunlight to push a sail through space and have the advantage of not requiring any fuel, continuing to accelerate in space until they reach very high velocity. Various configurations have been proposed for solar sails but the typical solar sail design has a flat square. The square is made from four triangular pieces of material, stretched between diagonal booms. The pressure of sunlight is low and typical configurations call for structures covering areas of 10,000 m^2 or more, with some designs calling for square sails with side lengths in the order of kilometres. Their structures would have ultra-low areal densities, down to 1 gm/m^2.

Future developments

Advances in materials science and engineering, processing, and fabrication techniques are leading to improved

Party balloon made from thin Mylar material

Space sailing is an elegant concept and represents an interesting but challenging application for gossamer structures technology.

gossamer structures. Other areas that are advancing are the development of better techniques for joining membranes, inflation and deployment systems.

Advances in analysis and computation allow engineers to explore ideas that were not possible in the early days of gossamer structures, opening new avenues of investigation and improved spacecraft designs. Conferences and workshops provide a forum for exchange of ideas and assist the development of gossamer space structures. The first conference on gossamer structures was held in Atlanta, USA in 2000 as part of the annual AIAA Structures, Structural Dynamics and Materials Conference (AIAA SDM) and is held annually as part of the SDM. The European Space Agency (ESA) holds a workshop on inflatable space structures every two years.

The next workshop will be held at the European Space Technology Centre at Noordwijk, Netherlands in June 2008. Each event brings new designs, prototypes, test results and space experience.

Gossamer space structures are proving to be necessary for the exploration of space, as spacecraft become larger and the programmes more ambitious.

Continuing advances in various branches of engineering help to push the technology and the future will bring increasing emphasis on its use in space. Φ

This article follows from Andrew's earlier article on deployable structures (An Unfolding Challenge, The Engineers Journal, vol. 59: 1, January/February 2005, pp 38–40).

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