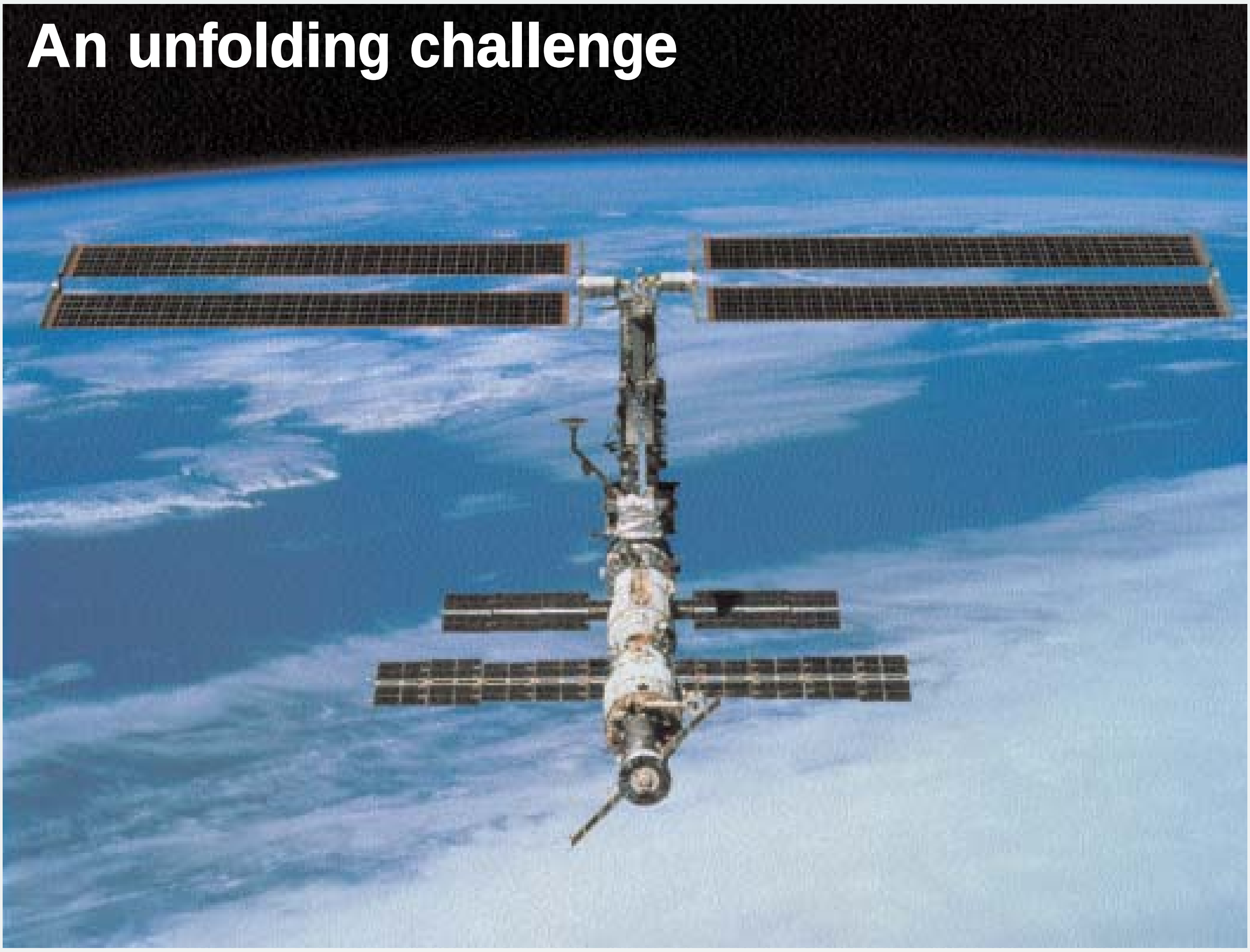
Deployable structures have been in use for centuries but as Chartered Engineer Andrew Lennon explains, modern demands, particularly in space applications, are pushing the limits of technology.

An unfolding challenge



Solar panels deployed on the International Space Station (Picture: NASA).

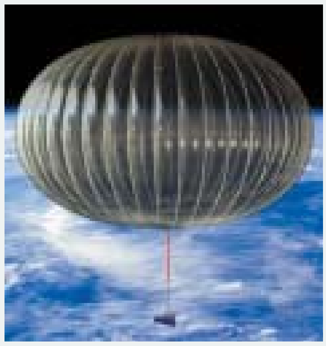
Deployable structures are all around us — in the form of umbrellas, ironing boards, deckchairs, and retractable tape measures — but we don't always recognise them as such.

Their unifying feature is the ability to change from one structural configuration to another. We usually think of structures as rigid and adopting a fixed configuration but deployable structures change between configurations. Umbrellas collapse for convenience, tape-measures retract for carrying and storage, and ironing boards and deckchairs have folding legs for ease of storage. In these cases, the deployable nature of the structures is for convenience but for other structures it is critical to their operation. An example is the parachute. The usefulness of a parachute depends on its ability to pack tightly into a small space and to reliably open to a wide area.

Requirements such as these drive the development of deployable structures engineering. Cambridge University is home to the Deployable Structures Laboratory (DSL), the world-leading group for research into the engineering and technology of deployable structures. The DSL is constantly developing and refining concepts for deployable structures and mechanisms for terrestrial and space applications.

Space

Space is the main driver of development in deployable structures. The earliest spacecraft such as the original Sputnik were sufficiently small to fit in the payload bays of early launch vehicles and did not require deployable appendages. Spacecraft quickly increased in size but the payload bays of launch vehicles did not increase at the same rate. The result was a requirement for large spacecraft to fit into small payload bays, which in turn acted as a driver for deployable structures technology. This mismatch between available payload bay size and desired spacecraft size continues today and limits the size of spacecraft



Left: The 60m mast from the SRTM during a ground test prior to the mission (NASA).
Above: Long-duration balloon (NASA).

that can be launched. Increasing the size of the payload bay on a launch vehicle is not a trivial task due to the complex physics involved and developers are now operating at the limits of current technology.

The largest payload bay of any launch vehicle is the Space Shuttle, with a maximum diameter of 4.6m and a length of 18.3m. The space shuttle has been out of commission since the loss of the Columbia orbiter in February 2003, and the largest currently available launch vehicles are the heavy lift rockets such as the European Ariane V launcher (payload bay diameter 4.6m, height 9.8). The main part of the spacecraft must fit within the dimensions of the payload bay and leave sufficient room for the deployable appendages. These appendages include antennae for communications and broadcasting, solar panels for power generation, or booms for supporting scientific instruments.

Challenges

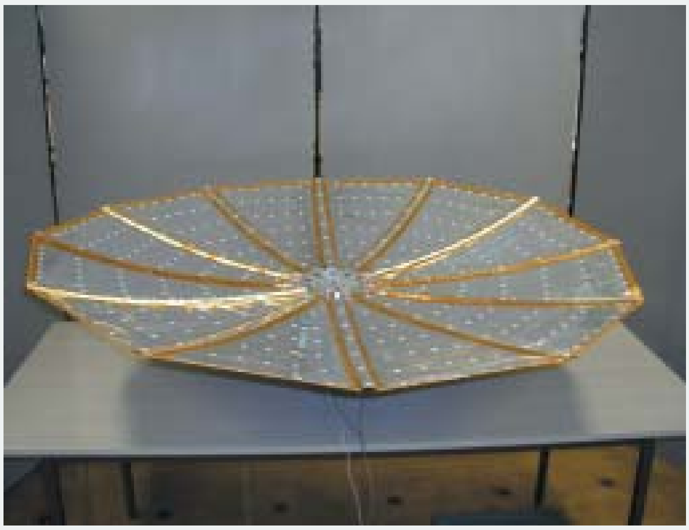
Launching a spacecraft puts significant loads on the structure. Vibration from launch can be considerable, and the launch phase includes periods of high acceleration and forces on the payload. Release from the payload bay exposes the spacecraft to the harsh environment of space. Spacecraft are bathed in ultra-violet radiation and magnetic fields, they experience a difference of hundreds of degrees between the temperatures of the sun-facing and shaded sides, and they are subjected to sudden changes from searing heat to frigid cold when passing into shade behind a planet or other body. Space is not a pleasant place and requires structures that can survive the environment outside the protective shield of our atmosphere. Deployable structures face additional challenges because they must survive the harsh launch period in the stowed configuration and still be able to move into their deployed configuration in the space environment. Structures that are also retractable must be able to both deploy and retract despite long-term exposure to the space environment.

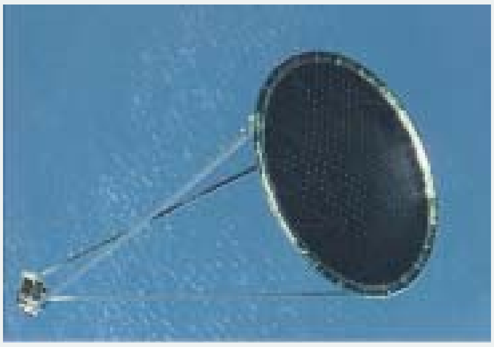
Reliable and robust deployment is essential. Intervention is not a realistic option in space and any deployment that does not proceed as planned can result in severely degraded performance and often a write-off of the spacecraft. This desire for reliability places an emphasis on simple design with the minimum number of moving parts.

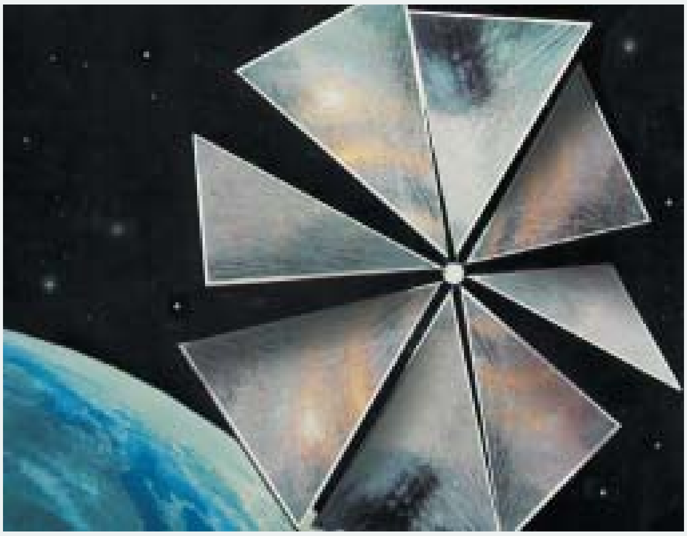
Left: The umbrella, a familiar example of a deployable structure.

Above: Another common example, the retractable measuring tape.

Right: Collapsible reflector developed at the DSL in Cambridge. The ribs fold for storage and spring into place when released.







Above: Inflatable antenna experiment (NASA).

Right: Artists concept of a solar sail (Babakin Space Centre, The Planetary Society).

Deployable structures also have a requirement for low mass. An Ariane V launch costs approximately €190–230 million and can lift a limited mass to space. This heavy-lift launcher can carry 16,000kg of payload to low earth orbit (LEO) or 6,800kg to geosynchronous transfer orbit (GTO). GTO is a stepping-stone to geosynchronous earth orbit (GEO) and part of the payload is fuel for the transfer between GTO and GEO, reducing the payload mass available for the spacecraft. An artificial satellite in GEO looks down at a fixed point on earth from this orbit and provides a commercially useful position for broadcasting or communications. Mass saved in the design of the spacecraft structure can be used for additional broadcasting equipment that earns revenue for the operator. Scientific spacecraft face the same challenge and mass saved from the structure can be used for scientific instruments.

Combining robustness, reliability and lightness poses significant challenges in the design of deployable structures. Various mechanisms are available to drive deployment such as electric motors, springs, folding ribs and coilable booms. Electric motors are an obvious and attractive solution for powering deployment but their mass and number of moving parts limits their use. One example of their successful use was the Shuttle Radar Topography Mission (SRTM) in February 2000. This mission deployed a mast from the space shuttle with radar surveying equipment at the end of the mast. It packed into a cylinder only 3m long and 1.2m in diameter yet it extended to 60m when deployed, making it the longest structure ever deployed in space.

Membrane structures

Membrane structures are a particular class of structures that use thin sheets of material and carry load primarily in tension. Membrane structures have a long history — from tents of animal skins right up to modern spacecraft using advanced materials. Familiar examples of membrane structures include soap bubbles, rubber balloons, sails, hot air balloons and helium-filled party balloons.

Engineered membrane structures have a number of advantages for space applications, notably their low mass and compact volume when stowed for launch. Space structures that require large spatial dimensions are an attractive area for exploiting the characteristics of membrane structures. Examples of large, advanced membrane structures are solar sails, parafoils and large parachutes. The dimensions of membrane structures are often much greater than those of most engineering structures and some solar sail designs call for structures with diameters of tens of kilometres.

Inflatable structures are a subset of membrane structures and have the desirable characteristics of low mass, large spatial dimensions and simple deployment. This field is still in its infancy and has many challenges to face but the potential uses of inflatable structures have generated significant interest in their development. Advanced engineering examples already used are long-duration scientific balloons, the gas-bag landing system for the Mars Pathfinder, and the inflatable antenna experiment (IAE).

Future Developments

Gossamer structures are ultra-lightweight structures that cover large areas and they are the next step in the development of membrane structures. The first gossamer spacecraft forum took place in 2000 and since then significant attention has focussed on this field. The IAE is an early example of a gossamer structure already deployed in space and proposals for the near future include solar sails, ballooning on other planets, inflatable telescopes, and membrane habitats in space and on the moon. Science and commerce continually challenge engineers to develop better deployable structures and the future looks busier than ever. ■

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