Ultra-lightweight, actively controlled mirrors for space

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Advanced technology mirrors for large space telescopes are being developed that use thin facesheets controlled by actuators. This concept was proven with a 50 cm prototype and is now being implemented for a 2-m cryogenic mirror that weighs only 40 kg.

A new type of mirror for large space telescopes is being developed at the University of Arizona that uses active control of a thin facesheet to achieve diffraction limited quality with ultra-low mass. The reflective surface is provided by a glass facesheet, typically 2 mm thick, which is attached to a stiff lightweight support structure through a set of screw-type actuators. This system allows periodic adjustments with the actuators to maintain the surface figure as measured from a wavefront sensor. The optical surface accuracy and stability are maintained by the active system, so the support structure does not need to be optically stable and can be made using light weight carbon fiber laminates that economically provide stiffness. Two critical demonstrations were made at the University of Arizona using 2-mm thick glass membranes – diffraction limited optical performance of a 0.5-m diameter mirror and launch survival of a 1-m diameter mirror. A 2-m prototype mirror for the Next Generation Space Telescope is now under construction. This mirror will have mass of only 40 kg, including support structure, actuators, and control electronics. It will be actively controlled and interferometrically measured at 35 K.

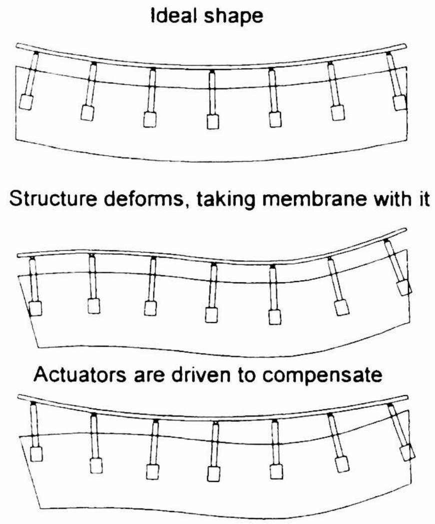

Figure 1. Use of position actuators to maintain the optical surface.

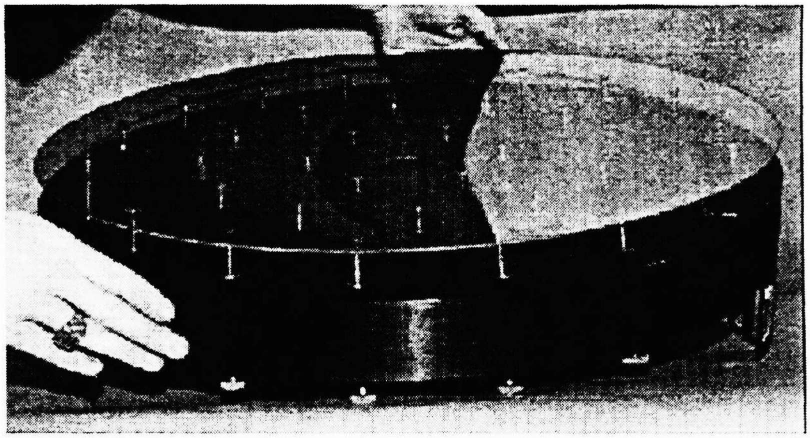

Figure 2. . 53-cm prototype mirror with 2-mm thick uncoated glass membrane.

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This mirror concept departs from the conventional paradigm of the mirror as a rigid optic with shape maintained by the stability of the substrate material, and must be supported by carefully controlled forces. The "rigid substrate" type of mirror has proven to be an excellent solution for ambient temperature telescopes without extreme lightweight requirements, for ground based telescopes and for the relatively small 2.4-m Hubble Space Telescope (HST). New mirror technology is required for the next generation of space telescopes that require 8 meter primary mirrors, with mass less than 15 kg/m^2. The conventional rigid-mirror technology is inadequate because it relies on the substrate to provide too many functions – stiffness to take polishing and launch loads and material properties that preserve the optical surface over years of operation with large temperature shifts and gradients.

The U of A mirror concept separates the functions of the mirror substrate to optimize the system for low mass and accurate figure. The absolute accuracy is maintained by closed-loop control based on wavefront measurements and the stiffness is provided by the carbon fiber composite backing structure. This allows the reflective part of the mirror to be a low-mass, 2-mm thick glass facesheet. The glass provides an excellent optical surface and will maintain its shape over scales too small to be corrected by the actuators. The actuators are remotely driven fine pitch screws that achieve 6 nm rms resolution and require no power to hold their position. The support structure is made from paper-thin laminated sheets of composite carbon fiber, similar to ultra-lightweight microwave reflectors with mass density < 5 kg/m^2 that are regularly put into space. These structures achieve excellent stiffness for their weight and they are proven to be stable over short time scales (days to months), minimizing the number of times that mirror shape needs to be re-adjusted.

A 53-cm demonstration mirror was built to test the U of A mirror concept. The optimization of the figure using 36 actuators was performed to achieve measured shape accuracy of 53 nm rms, which matched the expected gravity deflections (which would be absent in space).

We are now manufacturing a 2-m mirror as a prototype for NASA's Next Generation Space Telescope. This mirror, shown in Figure 3 will be demonstrated with closed-loop control at 35°K in late 1999.

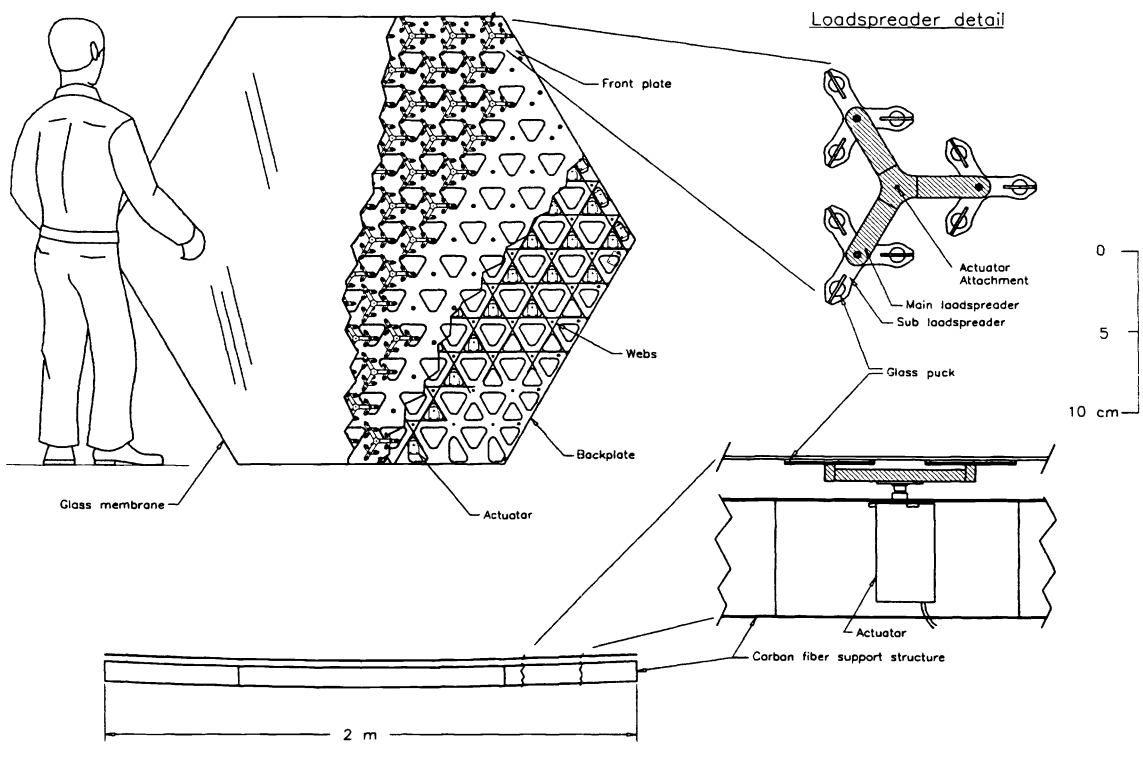

Figure 3. 2-meter NGST demonstration mirror