Building large, lightweight telescopes in space

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In-space manufacturing processes would enable the development of extremely large optical systems while relieving constraints such as launch vehicle volume limitations and high launch forces.

There is a continuous demand for larger, lighter, and higher quality telescopes from both the astronomical and global surveillance communities, one looking up and the other down. Technologies must be developed and implemented that will make this goal financially and technically feasible. The optical systems needed for high spatial resolution surveillance and astronomical applications require large optical apertures, presumably up to 150m in diameter. Such apertures entail large mass and long fabrication lead times, along with the high costs associated with traditional optical manufacturing technologies. Building these systems will require completely new approaches to optical fabrication.

The cost and lead time associated with the fabrication of lightweight, high-quality optical systems limit the feasible size of the optics. Volume and mass are primary factors in the launch cost of space optical systems. To minimize the mass of high-quality optics, optical fabricators use materials with high specific stiffness and honeycomb or other structural minimization patterns to support the optical surface. However, the structure must still be designed to survive the forces it is subjected to during launch.\(^1,2\) This adds significantly to the difficulty of fabrication and dramatically increases launch costs. One way to minimize launch volume and avoid the need for the design to survive launch forces is to send the manufacturing facility and raw materials into space and build the telescope \textit{in situ}.

Traditional optical fabrication processes involve controlled grinding and polishing techniques, which require many large computer numeric control (CNC) machines that generally must scale up with the size of the optic. It would not be feasible to launch such machines. In-space optical manufacturing, on the other hand, uses the space environment to greatly simplify the fabrication process for high-quality optics. We are currently performing feasibility studies of initial concepts for in-space manufacturing of both optical surfaces and telescope structures. We describe one primary approach to a fabrication facility, along with some initial results.

The process uses an expanding iris aperture and a small volume of molten glass that is expanded to a large membrane, greater than 1m. A considerably scaled down version is shown in Figure 1. Using the microgravity of space and minimizing surface free energy, we anticipate that such membranes may be formed into precision spherical mirrors. This can be accomplished through the use of pressure and precisely shaped rings required to control the boundary conditions. The process is illustrated in Figure 2.

A significant advantage of this process is that the volume of heated space needed to create the molten glass membrane is very small. Many of the discrete systems shown in Figure 2 could be placed in a single furnace. This would minimize the amount of energy needed to produce the mirrors. A conceptual facility is shown in Figures 3(a) and (b). The raw materials for the system forming feasibility studies of initial concepts for in-space manufacturing of both optical surfaces and telescope structures. We describe one primary approach to a fabrication facility, along with some initial results.

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Figure 2. The process for glass membrane mirror formation involves the use of pressure and precisely shaped rings.

Figure 3. (a) The conceptual drawing illustrates the fabrication facility, with the central canisters containing raw materials. (b) The second drawing illustrates the facility with the four furnaces open.

are located in the central canisters. When more raw materials are needed, only these central canisters would need to be replaced.

We tested the initial feasibility of this process using a high-temperature iris aperture to create a membrane glass sample with a diameter of 25mm. The demonstration is shown in Figure 4. The mirror surface form (low spatial frequency features) we obtained is not representative of predicted results in a microgravity environment. But the glass micro-roughness (high spatial frequency features) should be comparable to what could be achieved in space. The micro-roughness of the samples was tested using a white light interferometer over ~200 × 200μm. The samples have acceptable micro-roughness levels for visible and infrared applications at <1.5nm rms.

Although significant research remains to be done, in-space optical manufacturing could enable the development of extremely large optical systems. We anticipate that by implementing these or similar processes in the microgravity environment of space, large, high-quality spherical mirrors could be manufactured with feasible cost and lead times.

Figure 4. As the iris expands, molten glass is stretched into a membrane.

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References