Ultra-lightweight Precision Membrane Optics

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Abstract

Thin film or membrane optics, at present state-of-the-art, are limited to non-imaging concentrators, microwave antennas, and far infrared applications because of the surface and shape accuracy limitations. With reasonable development of cast and release technology and precision mandrels, optical quality membrane mirrors for visible and near infrared imaging may be possible in the immediate future, in sizes limited by mandrel dimensions. With the development of specific enabling technologies, which appear possible and practical, segmented or seamed optics suitable for visible or infrared systems appear feasible in dimensions limited mostly by handling and metrology.

1.0 Current Capabilities

Thin film membrane optics offer the potential for order-of-magnitude aperture size increase or weight reduction for super lightweight space based optical systems. A thin film or membrane mirror is potentially storable, deployable, reproducible, inexpensive compared to glass or metal optics, can be fabricated in sizes dictated largely by the available facilities, and may be seamed or joined to form very large areas.

Cast and release fabrication technologies, developed to take advantage of advanced soluble polyimide films, have enabled fabrication of large doubly curved polyimide membranes for many applications. The cast films do not require inflation pressure to obtain the desired shape. Currently, films are cast to the exact shape required for the desired application. Two identical films are fabricated and they are joined at the borders to form a symmetric lenticular element. The lenticular is supported from a more ridged torus via a catenary suspension system

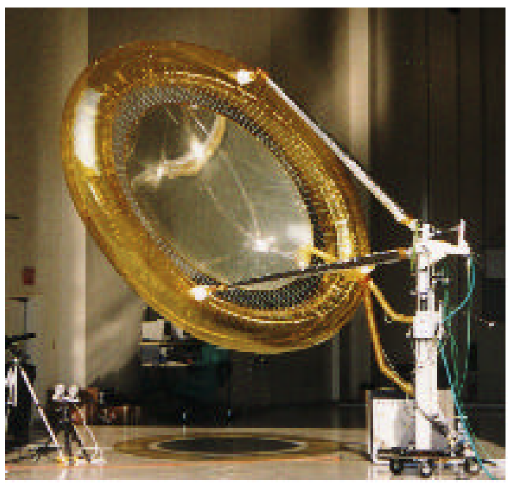

Figure 1 2 x 3 Meter Off-Axis Concentrator

A very small inflation pressure is applied to the lenticular element to position the films and pull out wrinkles that may have developed during storage. Reflective, conductive, or other desired coatings can be applied to the front surface or the back surface of either film element. The very low inflation pressures and the small number of seams, resulting from the use of large cast films, contribute to very low leak rates and make up gas requirements. **Figure 1** shows a 2 x 3 meter off-axis parabolic solar concentrator developed to test components for solar thermal propulsion. This concentrator was used for deployment testing and performance evaluation. Laser ray tracing and digital photogrammetry were used to record the deployed shape. Results from the testing were used to verify design analysis. Larger single piece films have also been fabricated and used for ultra-lightweight antenna applications. A five meter antenna was fabricated and tested. The five meter on-axis antenna was found to have a 1 millimeter RMS shape accuracy. This is adequate for many radiometric applications. However, advancement of this technology for precision optic applications will require several significant technology advances.

2.0 Advanced Technologies

Three technology areas for potential improvements over the current state-of-the-art include initial shape optimization, surface replication, and seaming techniques.

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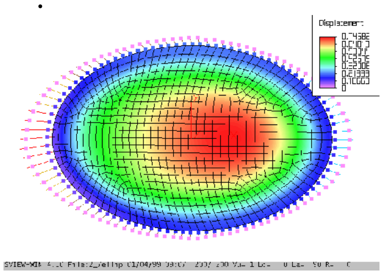

Figure 2 FEM Shape Analysis

Initial shape optimization offers significant improvement in shape precision. Shape optimization requires analytical evaluation of all of the loads and boundary conditions which drive the membrane away from the perfect shape, which it is currently cast to in present designs. Analysis must then be performed to determine an initial shape that, when subject to the boundary conditions, will deform to the perfect design shape. Significant progress has been made in this area. **Figure 2** shows results from non-linear finite element analysis of the 2 x 3 meter concentrator shown in figure 1. The results of this analysis were verified using digital photogrammetry. The results were then used to determine an improved initial geometry for the concentrator membrane. The deflections of the improved membrane design were then used to calculate the deployed shape of a second generation mirror based on the improved geometry. **Figure 3** shows calculated slope error (dz/dx) along the major axis of the concentrator for the original design and for the optimized design. As seen in the figure the edge affects were greatly reduced and the slope error in the majority of the concentrator was almost entirely removed.

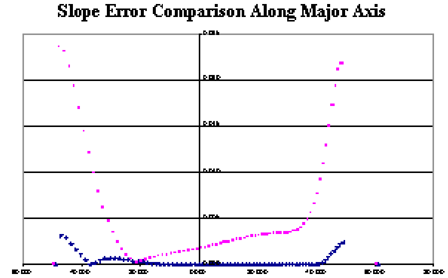

Figure 3 Slope Error Improvement

Improved film surface finish is another potential technology area for further development of precision thin film optics.

To date, most of the applications of thin film concentrators and antenna have not required an extremely polished surface finish. However, for precision imaging applications, film surface finish will be very important. Limited studies performed to date have shown that cast films seem to replicate the finish of the casting surface very well. In fact, under stress the surface finish may even improve over the quality of the mandrel. However, this trend has not been verified for highly polished mandrel surfaces. Additionally, the effect of a highly polished mandrel surface on film wetting and other casting parameters has not been fully characterized. Additional research in this area is required to see if the surface replication properties of film casting can be maintained for films cast on highly polished surfaces.

Finally, seaming technologies for precision optics must be developed to progress to precision membrane optics that exceed the size of available mandrel and curing facilities. A practical upper limit for single piece optics would be around the 10 meter class. Soluble polyimide films offer some distinct advantages in this regard. Soluble films can be cast in doubly curved sections of the largest practical size. Solvent welding can then be used to join the segments with near homogenous properties across the weld. This process has been demonstrated but considerable development is required before the technique is ready to be put into practice. Lap type seams have also been evaluated. These seams cause a local disturbance in the film properties due to double thickness at the seam. However, relatively low resolution measurements of film shape near seams has been performed on some concentrator like films and the shape errors resulting from the seam appear to be very localized. It has been postulated that this is due to the fact that the geometric stiffness of the film is governing the shape rather than the film stiffness. It appears feasible to develop seams that do not preclude precision optic performance from the film, particularly if the seam surface itself is not required to be of optical precision.

3.0 Summary

The development of large imaging quality membrane optics fabricated from very thin space-rated polymers is a high payoff crosscutting technology that will benefit many current and future NASA, DOD and commercial missions. IR imaging membrane optics will enable development of previously impractical aperture sizes for sensors used in Earth resources exploration, weather monitoring and forecasting, intelligence gathering, and other imaging applications. Further development of thin film optics for visible wavelength imaging will enable development of very large space telescopes and other imaging applications. The current state-of-the-art thin film membrane structures are suitable for many power generation, propulsion, and antenna applications. Several emerging technology areas offer potential improvements which should lead to development of precision thin film optical components for space application