PHOTOGRAMMETRIC MEASUREMENT OF GOSSAMER SPACECRAFT MEMBRANE WRINKLING

Richard S. Pappa
NASA Langley Research Center
Hampton, Virginia

Jonathan T. Black
George Washington University
Hampton, Virginia

Joseph R. Blandino
James Madison University
Harrisonburg, Virginia

ABSTRACT

Photogrammetry methods are being developed for measuring the shape and dynamics of future gossamer spacecraft structures, which characteristically contain large areas of thin-film membranes. Examples include solar sails, large membrane antennas, telescope sun shields, inflatable solar arrays, space solar power collectors and transmitters, radar arrays, and planetary balloons and habitats. Membrane wrinkling (and slackening)--caused by various sources including seaming and folding, nonuniform tensioning, thermal effects, and creep--can potentially reduce performance or cause overheating or structural fatigue in space. This paper documents an experimental photogrammetric technique capable of measuring membrane wrinkle patterns and amplitudes using thousands of projected dots of light and multiple synchronized cameras. Typical results are presented for a 0.5 m x 1.0 m area of interest on a 2m square solar sail model. In this application, the photogrammetric measurement precision was approximately 25 microns (0.001 inches). The paper closes by mentioning a promising extension of existing techniques using a laser-induced fluorescence approach.

INTRODUCTION

NASA is giving renewed attention to the topic of large, ultra-lightweight space structures, also known as "gossamer" spacecraft. Revolutionary concepts for large antennas and observatories, solar sails, inflatable solar arrays and concentrators, and inflatable habitats, among others, are being studied [Ref. 1]. These structures characteristically contain large areas of thin-film membranes and can be tens or even hundreds of meters in size. Complete gossamer systems are generally too large and flexible for meaningful ground testing, so increased reliance must be placed on analytical methods validated by representative scale-model test articles [Refs. 2-3].

Figure 1 shows several examples of gossamer ground test articles. The delicate nature of these structures requires non-contacting, optical measurement techniques. Photogrammetry has proven to be an effective and robust technology for this purpose. Photogrammetry is the science of measuring three-dimensional object coordinates with photographs [Ref. 4]. Research to develop effective photogrammetry and videogrammetry methods for shape and dynamic measurements of gossamer structures began about three years ago. Several earlier publications discuss related and complementary aspects of this work [Refs. 5-8].

This paper has two sections. The first section summarizes an experimental photogrammetric technique for measuring membrane wrinkles using thousands of projected dots of light and multiple synchronized cameras. The second section mentions a promising extension of this technique using a laser-induced fluorescence approach. Membrane wrinkling (and slackening)--caused by various sources including seaming and folding, nonuniform tensioning, thermal effects, and creep--can potentially reduce performance or cause overheating or structural fatigue in space and therefore must be well understood both analytically and experimentally.

TEST PROCEDURES AND RESULTS

Figure 2(a) shows a lightly tensioned 2m square solar sail model. This structure was designed using constant-thickness scaling laws [Ref. 9] and displays considerable wrinkling in a vertical orientation in gravity. The exact shape of the wrinkles can change easily with slight air currents or other environmental disturbances, so a full-field, rapid measurement technique is required. A grid of about 5000 dots was projected onto the indicated area, which is about 0.5 m x 1.0 m in size. Four Olympus E-20 digital cameras located as shown in Fig. 2(b) photographed the dot pattern simultaneously. Several sets of photographs were taken in a darkened room at different shutter speeds. The set selected for processing used a 30-second image exposure time, which provided the best contrast between the projected white dots and the aluminized Kapton background. Figures 2(c) and 2(d) show a typical image and a close-up view of photogrammetrically computed centroids of the projected targets. Target centroids are marked to a precision of about 0.1 pixel in the image processing using a least-squares matching (LSM) algorithm. Several bright dots visible around the edges of the area photographed are guide points used to calculate initial camera orientations.

An accurate model of the membrane surface was obtained by analyzing the complete set of four images using LSM target marking and an iterative bundle solution method [Ref. 10]. The results, consisting of over 5000 three-dimensional points, are displayed as a fitted surface and corresponding relief and contour plots in Fig. 3. These results clearly show the visible wrinkles in the Kapton membrane and the seam cutting horizontally across the center. Typical maximum wrinkle amplitudes were 5 mm peak-to-valley, and the photogrammetric measurement precision (calculated by the software) was approximately 25 microns (0.001 inches).

LASER-INDUCED FLUORESCENCE

Figure 4 shows a novel laser-induced fluorescence approach under development that complements and in some ways exceeds the proven capabilities of the white-light dot projection method discussed above [Refs. 7, 11]. This approach requires doping the membrane material with a small amount of fluorescent laser dye during manufacturing (or perhaps spraying or painting it on afterwards). When illuminated with a laser, the fluorescing dye emits light in all directions at a lower frequency than the light source. By using an optical low-pass filter on the camera, high-contrast targets are obtained even on transparent membranes. High-density grids of circular dots can be projected using a single laser and a diffractive pattern generator. Coupled with the use of high-power pulsed lasers, this approach can be an enabling technology for making both static and dynamic measurements of the largest anticipated gossamer ground test articles (perhaps up to 30 m in size) that will be built in the foreseeable future.

REFERENCES

[1] Jenkins, C. H. M. (editor), *Gossamer Spacecraft: Membrane and Inflatable Structures Technology for Space Applications*, Vol. 191, Progress in Astronautics and Aeronautics, AIAA, Reston, VA, 2001.

[2] Slade, K. N., Belvin, W. K., and Behun, V., "Solar Sail Loads, Dynamics, and Membrane Studies," AIAA Paper 2002-1265, April 2002.

[3] Leifer, J. and Belvin, W. K., "Prediction of Wrinkle Amplitudes in Thin Film Membranes Using Finite Elements," AIAA Paper 2003-1983, April 2003.

[4] Mikhail, E. M., Bethel, J. S., and McGlone, J. C., *Introduction to Modern Photogrammetry,* John Wiley and Sons, New York, NY, 2001.

[5] Pappa, R. S., Giersch, L. R., and Quagliaroli, J. M., "Photogrammetry of a 5m Inflatable Space Antenna With Consumer-Grade Digital Cameras," *Experimental Techniques*, Vol. 25, No. 4, July/Aug. 2001, pp. 21-29.

[6] Dharamsi, U. K., Evanchik, D. M., and Blandino, J. R., "Comparing Photogrammetry with a Conventional Displacement Measurement Technique on a Square Kapton Membrane," AIAA Paper 2002-1258, April 2002.

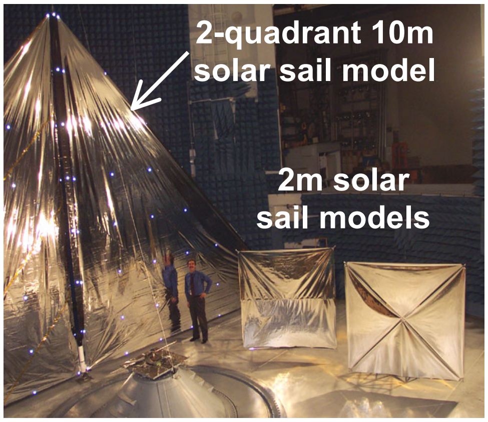
[7] Pappa, R. S., Black, J. T., Blandino, J. R., Jones, T. W., Danehy, P. M., and Dorrington, A. A., "Dot-Projection Photogrammetry and Videogrammetry of Gossamer Space Structures," NASA TM-2003-212146, Jan. 2003.

[8] Blandino, J. R., Pappa, R. S., and Black, J. T., "Modal Identification of Membrane Structures With Videogrammetry and Laser Vibrometry," AIAA Paper 2003-1745, April 2003.

[9] Greschik, G. and Mikulas, M., "Scale Model Testing of Nonlinear Phenomenon with Emphasis on Thin-Film Deployable Structures," IUTAM-IASS Symposium on Deployable Structures, Cambridge, U.K. Sept. 1998.

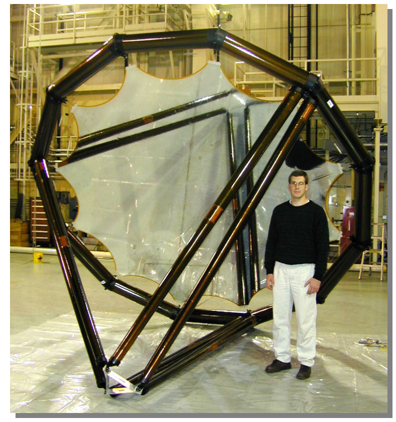
[10] Eos Systems Inc., *PhotoModeler Pro 5.0 User Manual*, April 2003, Website: www.photomodeler.com.

[11] Danehy, P. M., Jones, T. W., Connell, J. W., Belvin, W. K., and Watson, K. A., "Photogrammetry Method for Transparent, Reflective, or Dark Surfaces," NASA Invention Disclosure No. LAR-16426-1-ND, Dec. 2001.



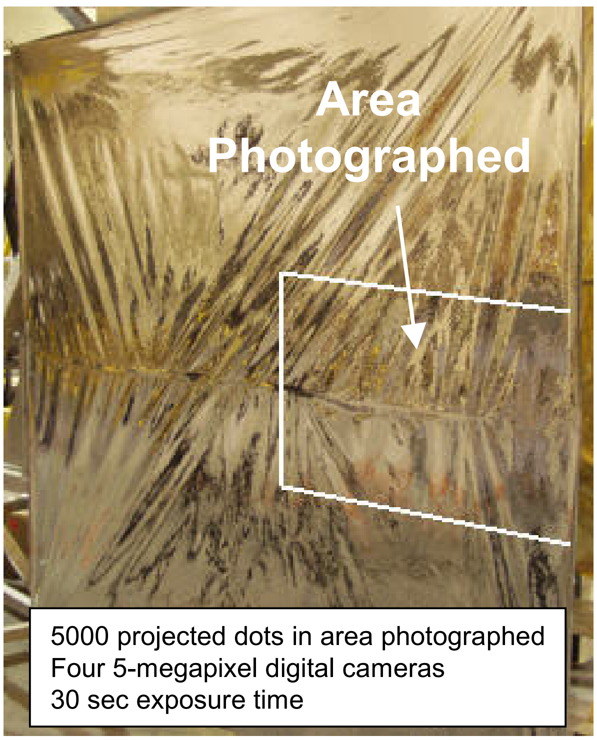
(a) Solar sails

(b) 5m inflatable antenna

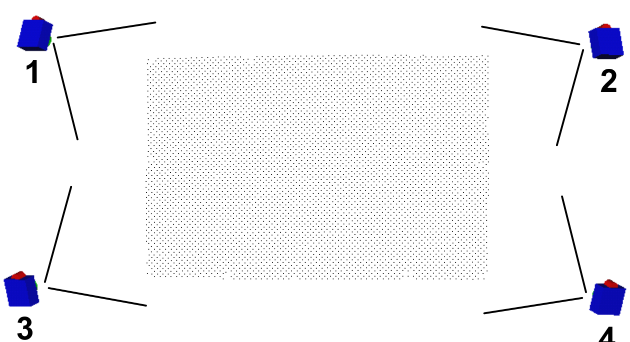


(c) 3m membrane reflector

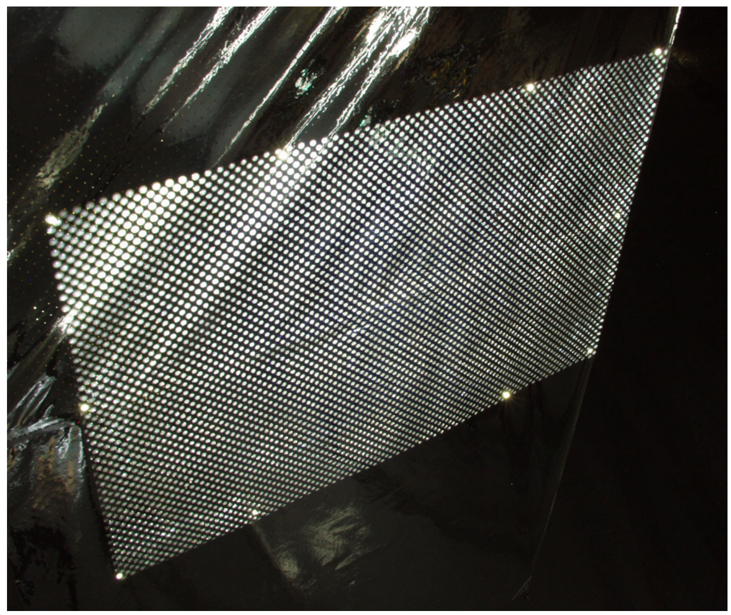
Figure 1. Gossamer spacecraft test articles at NASA Langley Research Center.



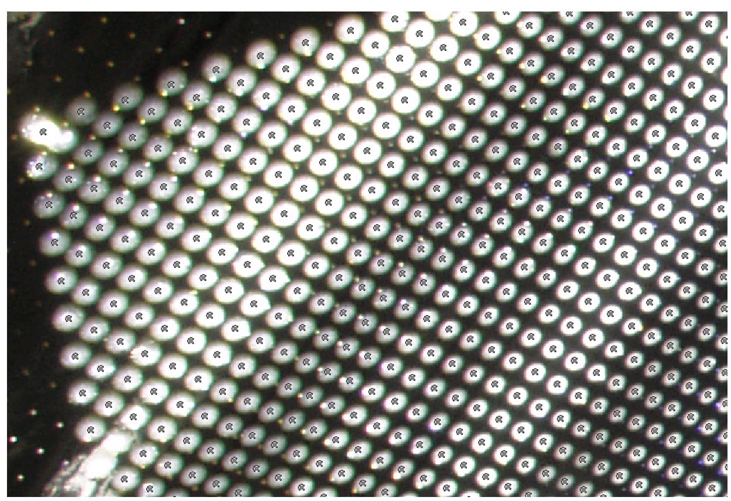
(a) Test article



(b) Camera locations with fields of view indicated

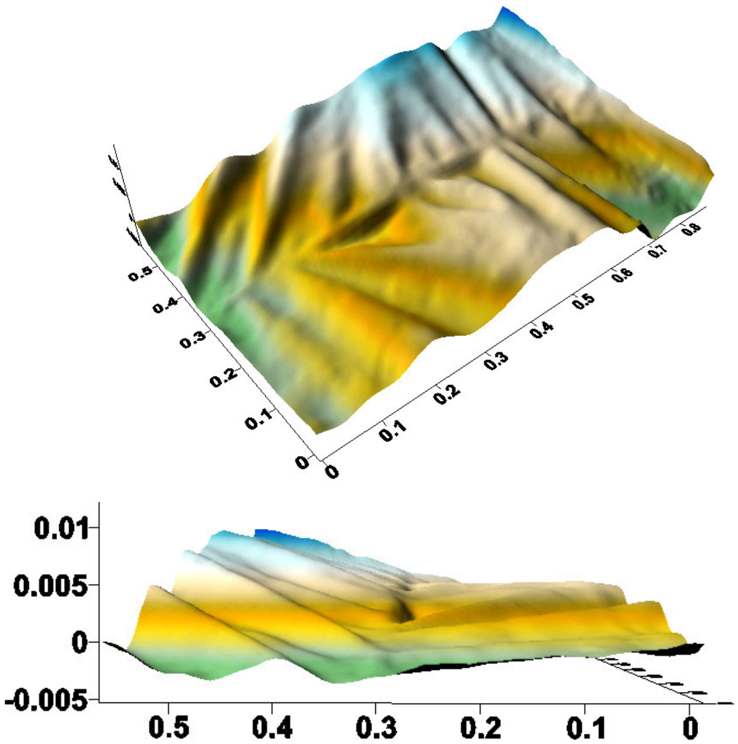


(c) Image from Camera 1 (upper left)

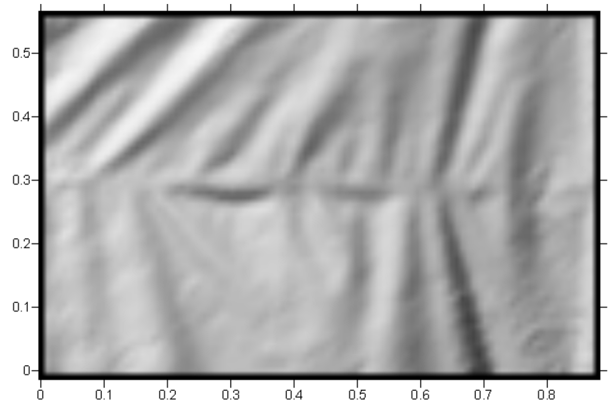


(d) Expanded view of upper-left corner of Fig. 2(c) showing marked targets

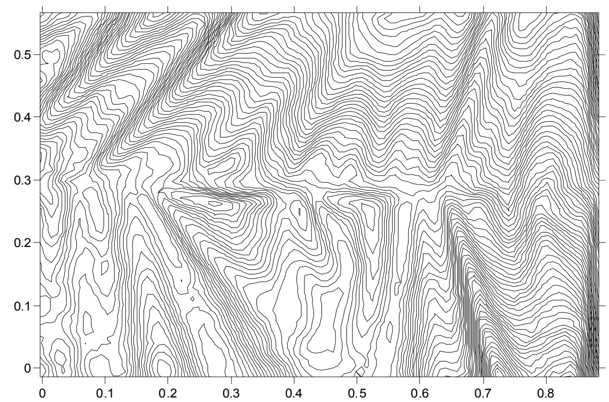
Figure 2. Photogrammetry of 2m aluminized Kapton solar sail using 5000 projected white dots.



(a) Two views of fitted surface (Dimensions in meters)

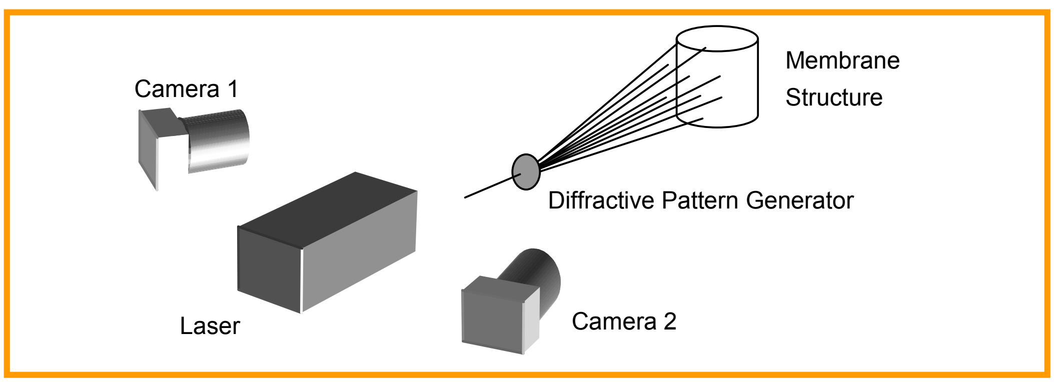


(b) Corresponding relief map



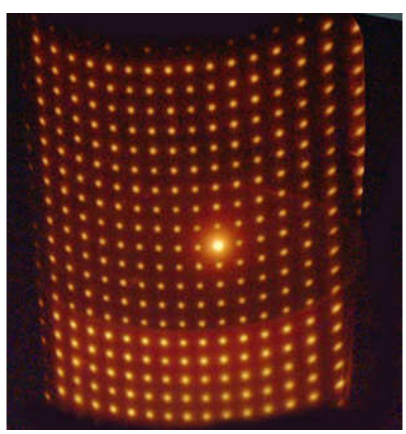
(c) Corresponding contour plot

Figure 3. Photogrammetry results.

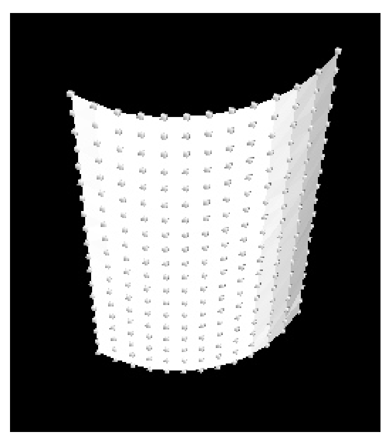


(a) Test configuration for proof-of-concept experiment

(b) Transparent CP-2 + dye



(c) Fluorescence from laser dot projection



(d) 3D surface by photogrammetry

Figure 4. Laser-induced fluorescence for dot-projection photogrammetry of transparent membranes.