DEPLOYMENT OF A MEMBRANE REFLECTOR IN ZERO-G

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ABSTRACT

Thin membrane reflectors will have a large role in the next generation aerospace industry. Lightweight, flexible membranes will reduce cost for larger structures used for communication, imaging, and transportation in space. The goals of this project were to 1) Develop a first generation membrane test bed that can be continuously improved for later test flights; 2) To provide meaningful gravity release data for development of membrane space structures; 3) To provide SDSM&T students with an educational opportunity in aerospace engineering and science; and 4) To disseminate this information with a comprehensive outreach program to a broad student and public audience. The experiment took place aboard the KC-135A Reduced Gravity Laboratory at Ellington Field, Texas. An apparatus was constructed that would spin a reflecting membrane and a control grid on a spindle. A digital video camera recorded the behavior of the membrane under varying gravity and centrifugal forces. The data gathered from the flights was analyzed using imaging software. The results compared the distortion of the reflected image of the control grid off the membrane to the image of the control grid itself. The premise was that the amount of image distortion was proportional to the deviation from the desired surface profile. The results showed basic trends such as an increase in distortion with increased force on the membrane. However, a full quantitative analysis would require further work that is beyond the scope of the project at this time. The project was considered a success in that a membrane test bed was constructed and flown on the KC-135 and meaningful data were actualized in the process. SDSM&T students received an invaluable learning experience designing and constructing the project. The students have also had the opportunity to share their experience with many audiences. The experience has yielded insights for making precise measurements in a constantly changing environment such as the KC-135. These considerations will weigh heavily in any SDSM&T projects performed on the KC-135 in the future.

Keywords

KC-135 Reduced Gravity Membrane Deployment SDSM&T NASA
INTRODUCTION

Inflatable and membrane structures have been the highlight of interest for many NASA and DOD scientists regarding the future in space applications. The trend to reduce the cost of launch and design of space structures largely motivates this interest. Inflatable and membrane structures have the potential for significantly reduced launch mass and stowed volume. Applications for membrane and inflatable structures in space include optical and IR imaging, solar concentrators for solar power and propulsion, lunar and planetary habitats, sun shades, solar sails, and many other fields of study. These membrane structures may be from 10 - 100 m or more in breadth. Because the membranes are so thin and compliant, they have little stiffness to resist deflecting under their own weight. This characteristic makes it difficult to determine the deployment behavior and final shape of such membranes during ground tests on Earth.

This project, to study the final shape of a deployed membrane, was performed aboard the NASA’s KC-135A Reduced Gravity airplane. The KC-135 flies in a parabolic trajectory that allows up to thirty seconds of weightlessness. The KC-135 provided a variable gravity platform, which allowed experiments to be performed under a variety of conditions including microgravity.

The objectives of this project include the following:

- To develop a first generation membrane test bed that can be continuously improved for later flight tests, including a possible space shuttle canister experiment,
- To provide meaningful gravity release data for development of membrane space structures,
- To provide SDSM&T students an educational opportunity in aerospace engineering and science,
- To disseminate this information with a comprehensive outreach program to a broad student and public audience.

TEST DESCRIPTION

SDSM&T students designed and flew the test article, which contained a model membrane reflector. The article was operated in both stationary and rotating modes. Video images, made with a digital video camera, captured the amount of distortion in the reflection of the image of the control grid. The amount of distortion could be compared between visual measurements made in microgravity and in normal gravity conditions. Similarly, the video capability of the camera allowed data to be collected when the article was rotating.

Images were made during two different operating conditions. In one condition, the membrane was stationary; in the other, it was rotating at a constant angular velocity. The latter case provided centrifugal forces on the membrane, which, in principal, modify its shape. Tension forces from the support bars or other were assumed constant and disregarded.
METHODS

The SDSM&T flight crews flew two times aboard the KC-135, which flies approximately forty parabolas per outing, with a maximum of thirty seconds of microgravity per parabola. The flight crews’ responsibilities included inspecting and operating the video equipment and drive motor.

The data collected during the KC-135 flights included video footage of the membrane and grid together inside the test chamber. Still footage of the panels was taken during a break in parabolas to gather a baseline for the vibration conditions inside the plane during flight.

Figure 1. Experiment test bed without casing.

Figure 2. Forces acting on membrane. Black: centrifugal; gray: gravitational.
The data collection plan for flight day one was to record 10 parabolas, each at 60, 120, and 180 revolutions per minute. If problems were encountered during the flight, the alternate plan was to record still data for the remainder of the flight if the problem could not be easily fixed in flight. The plan for flight day two was determined from the data collected during the first flight. One hundred-eighty rpm and some 120 rpm data for day one was missed. So, flight day two would begin with 180 rpms, proceeding to 120 rpms, and ending with static data collection.

The camera provided 32 frames per second of images for analysis. Given that each flight lasted approximately an hour, the available video footage yielded over 230,000 images. In order to make the data more manageable for preliminary analysis, three frames were chosen from each parabola for analysis. These frames would be one image from the initial 2-G as the parabola began, one image from the time during microgravity, and one image from the final 2-G as the parabola finished. The specific frames used were chosen arbitrarily.

Each image contained all the boxes on the grid and their corresponding reflections on the membrane. A review of the video showed that three grid boxes in particular appeared to yield the most consistent reflections over each parabola. These three boxes and their corresponding reflection boxes became the choices for test points from which to begin the data analysis. For each image the same six test points were used - the three grid blocks and their corresponding reflected images. The control grid points, located on the left side of Figure 3, are labeled “G1, G2, or G3,” and the Membrane Reflection Image points are on the right side labeled “I1, I2, or I3.”

These test points were processed using Scion Image Software. Each image was first put through a threshold function to turn each pixel either black or white, determined by its original value. Next, the boxes were isolated by adding a small line of white at the middle of any connecting point between black boxes. This confined each box for the software so a pixel count of the area and the perimeter could be made. The areas and perimeters for each image and parabola were then recorded in Excel for analysis.
RESULTS

The three points were separately analyzed and plotted per trial versus the ratio of pixel change compared to the control grid. Control grid plots indicate that there is minimum change due to camera movement and the number of pixels captured per control grid image stays nearly constant.

Figures 4-6 show the trends of each point per trial at different constant angular velocities before, during, and after the thirty seconds of the microgravity period. The general trend was for the initial value to be smaller than the microgravity value. The higher value is most likely due to the motion of relaxation as gravity releases. And as gravity returns, the final values are consistently lower than the values during microgravity. However, the final value is usually not as low as the initial value. This is possibly an indication of a lag time as the membrane is still stretching to achieve the lowest value under gravity.

Another important trend that Figure 4 and Figure 5 illustrate is the increase in the Ratio of Area Change with increased rotation. At 60 rotations per minute, the Ratio of Area Change value is at its lowest point. It increases to 180 rpm where it is at its highest. The membrane, which normally sags due to gravity, has a slim reflective profile under higher gravity. As the rotation increases, this profile opens up and increases the reflective area, increasing the Ratio of Area that is reflected to the camera.

The data collected on the third set of points, G3 and I3, show deviant behavior. The trends followed by the other two points do not apply. Analysis of the video and pictures reveal that this particular box is located directly on a tension kink in the membrane. The surface at this point is nearly parallel to both gravity and the centrifugal forces, and the perpendicular surface area is minimized, reducing the effect of both forces on the membrane. This is the case with the similar values for all except the first set of 60 rpm values. The G3/I3 Day One, 60 rpm data may be the result of a vibration or some other anomaly.

Figure 4. G1/I1 ratio of area change to gravity per trial.
CONCLUSIONS & RECOMMENDATIONS

Definite trends have been reflected in the data analyzed. The higher the gravity, the smaller the reflective profile of the membrane. The higher the rotation, the larger the reflective profile of the membrane. When the membrane is under gravity and spinning at fairly high rates of speed, one can expect competing forces to distort the membrane in different ways. This avenue of analysis hints at a calculus-based model. Further research could lead to a comprehensive calculus-based analysis.

One of the major problems that hindered construction and data analysis was the presence of tension kinks in the membrane. Several membrane reflectors were constructed in both South Dakota and Texas. Every reflector developed kinks after a period of time and proved sensitive to changes in tempera-
ture and weather. This tension interfered with proper reflection of the membrane and no doubt skewed the data significantly. To avoid this, the membrane could be placed on adjustable tensioners attached to a ring. In this manner, kinks could be easily removed. Experiments using different types of reflector material could also solve this problem. Whatever solution is ultimately developed, a better mounting scheme is required for the membrane reflector.

The scientific results from this experiment have shown that the membrane does change shape between normal gravity and microgravity. However, precise measurements showing how the membrane changes shape were not achieved. To accomplish these measurements, a refined test bed must be designed, and the data reduction method must be evaluated. Suggested improvements for future tests are listed below:

1) A better mounting scheme for the panels and grid to reduce movements,
2) Better adhesion methods for attaching the membrane to the frame,
3) Examination of the optimal membrane geometry for testing purposes,
4) Use of a still digital camera and a timing mechanism for increased resolution,
5) Use of strain gauges or other devices for measuring the deflections of the surface,
6) Isolation of the membrane and camera from external bumping of the test box,
7) Separation of centrifugal and gravitational measurements to maximize the effects of both,
8) An optimized method and software for data reduction.

The results from this project continue to be examined. By further data reduction and evaluation and closer examination of the testing procedures, additional ways to improve upon this first generation test will be identified.

This project was a success at many levels. SDSM&T students developed, constructed, and flew a working thin membrane experiment that yielded definitive results that may be used to prepare further membrane research. A comprehensive outreach program was prepared with the help of school Journalist Kari Larese. More than a dozen presentations have been made and various members of the KC-135 team have had the opportunity to interact with younger kids interested in science and engineering. Thousands of people have been made aware of the project through various articles and stories written from February to March of 2000.

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**Flight Crew**

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* - alternate flyers

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