NASA/TM-2003-212150

Membrane Vibration Tests Using Surface-Bonded Piezoelectric Patch Actuation

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February 2003

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Space Administration

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MEMBRANE VIBRATION TESTS USING SURFACE-BONDED PIEZOELECTRIC PATCH ACTUATION

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ABSTRACT

This paper describes the status of on-going work at the NASA Langley Research Center to measure the dynamics of thin membranes. The test article is a one-meter square pre-tensioned Kapton membrane that incorporates small surface-bonded piezoelectric patches strategically positioned to excite many modes. It is shown that PVDF (polyvinylidene fluoride) and MFC (macro fiber composite) piezoelectric patch actuators provide adequate excitation energy to obtain modal frequencies and mode shapes. Results from modal tests performed on the membrane using piezoelectric patches of different sizes and positions are discussed.

1. INTRODUCTION

With the increasing interest in large ultra-lightweight space structures and the desire for further exploration and discovery in space, revolutionary concepts for large antennas and observatories, solar sails, inflatable solar arrays and concentrators, are being studied by NASA[1-3]. These systems will use new, ultra-lightweight materials. In the next few years, prototype hardware will be produced and will require structural testing and validation. Researchers have demonstrated that thin piezoelectric actuators can be used for modal testing ultra-lightweight inflation stiffened torus structures[4-6]. However, to the author’s knowledge, no one has yet investigated using piezoelectric actuators for modal testing pre-tensioned flat membranes. Also, only a few experimental studies concerning the vibration of pre-tensioned flat membranes for space structures applications have been performed[7-12]. These tests focused on using an electrodynamic shaker or impact hammer for modal excitation. Future space structures will have large sections of pre-tensioned flat membranes that will need to be vibration tested and validated. Their delicate nature requires the use of novel excitation methods and non-contacting structural measurement techniques. Laser vibrometry for vibration measurement with surface-bonded piezoelectric patches for excitation is one candidate technology for this purpose.

The research reported in this paper was conducted to begin to address the technical challenges and requirements of modal testing for future ultra-lightweight and inflatable space structures. Specific objectives of this work are to investigate the effectiveness (i.e., accuracy, precision, repeatability, etc.) of laser vibrometer measurements obtained on a thin pre-tensioned flat membrane actuated with surface-bonded piezoelectric patches of various sizes and positions on the membrane.

2. TEST ARTICLE AND EXPERIMENTAL PROCEDURE

2.1 Description of Test Article

The test specimen is a 1.02 m (40 in) square polyimide Kapton membrane with a thickness of 51 micron (2 mil). Figure 1 shows the test configuration for this study. Each of the corners of the material are reinforced using 128 micron (5 mil) thick transparency film on both sides. All four corners of the article are attached with 76.1 mm (3 in) wire through 6 mm diameter brass grommets. Linear

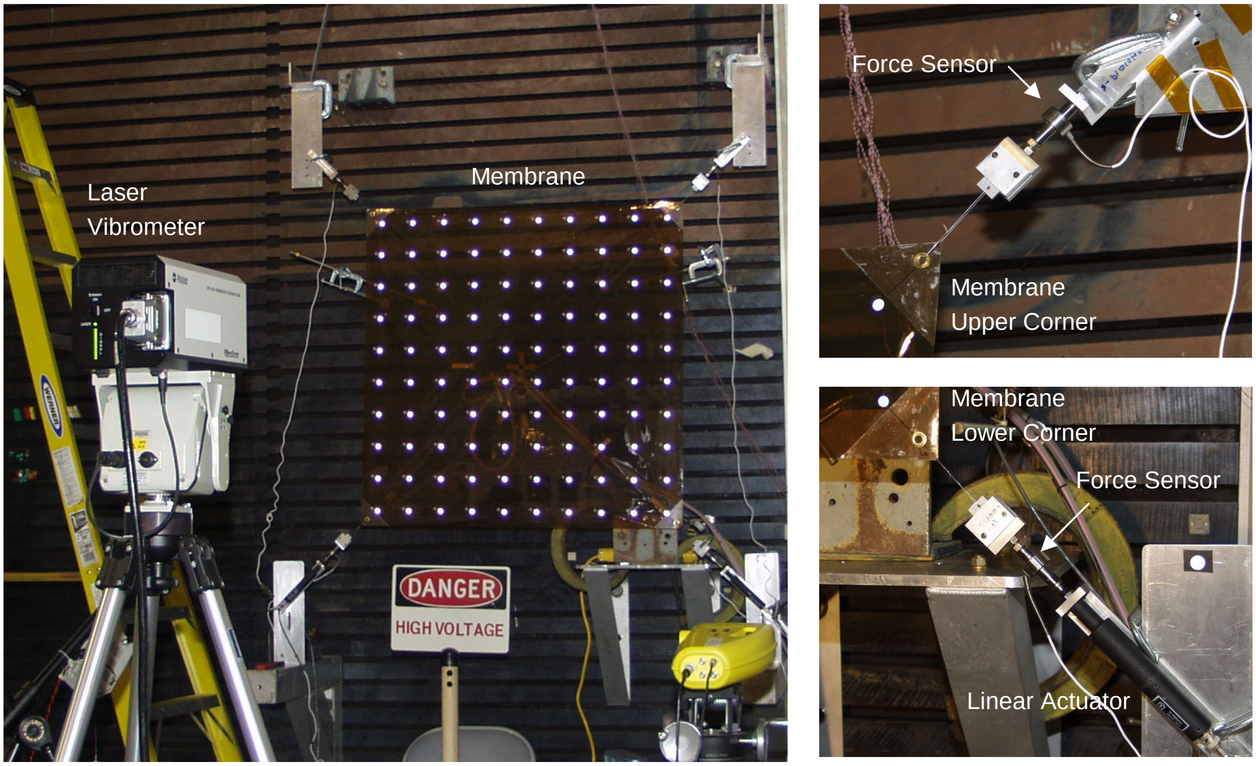

Figure 1: Experimental Test setup

actuators at the two lower corner locations are used to precisely preload the membrane. Force gauges are used to determine tension at each of the four corners. The tensioning devices are supported by aluminum brackets mounted to a heavy steel wall.

2.2 Actuator Description

The test article is excited using ceramic and polymer based piezoelectric patches. The ceramic based patches were developed at NASA Langley and are referred to as MFC's (Macro Fiber Composites)[13-14]. The polymer based piezoelectric patches are made with PVDF (Polyvinylidene Flouride) of various sizes manufactured by Measurement Specialties Inc. (MSI). The PVDF actuators consist of an active area covered with silver ink electrodes on both surfaces. The silver ink can withstand the high voltages required to drive the actuators. The PVDF actuators also have an unmetallized border to eliminate the potential for arcing across the film thickness. The PVDF patches are much thinner than the MFC patches, and have a better impedance match with the Kapton membrane test article. However, the PVDF's have significantly less strain actuation capabilities than the MFC's. Patches of different sizes and positions on the membrane were used to determine their capability for

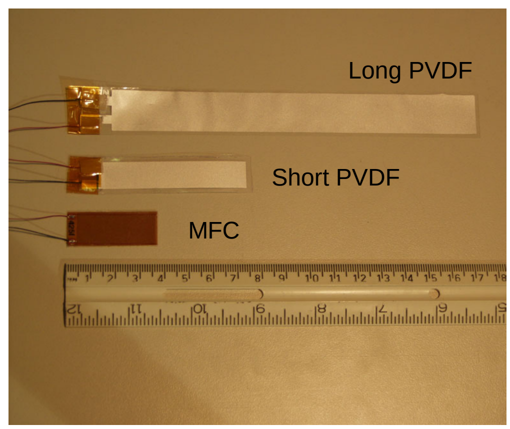

Figure 2: Piezoelectric Patches

exciting the membrane modes. Figure 2 shows the piezoelectric patches used. The long and short PVDF's are 52 microns thick, while the bottom actuator shown in the figure is the MFC with a thickness of 479 microns.

2.3 Surface-Bonding and Wiring Method

The piezoelectric patches are surface-bonded to the backside of the membrane with 3M 501FL double-backed adhesive transfer tape with an adhesive layer thickness of 51 microns. The MFC patches could easily be removed and reused for other tests. Some of the PVDF patches had a tendency to tear when removed from the membrane and could not be reused. For the PVDF actuators, thin strain gage wire is attached to the actuator leads with 3M Z-Axis conductive tape. Kapton tape encapsulated the PVDF wire-leads for improved bond strength. The strain gage wires are soldered to the MFC leads. For all tests performed, the actuator wires were carefully secured to minimize their effect on the membrane vibrations.

2.4 Actuator Locations

Surface-bonded piezoelectric patches apply a strain to the membrane test article when voltage is applied. The piezoelectric material will expand and contract in-phase with the input voltage signal. Thus, the surface-bonded actuators provide a small out-of-plane disturbance on the membrane due to the bending caused by the shear force created at the interface of the patch to the membrane. This bending can be seen as a small bulge on the surface of the membrane at the actuator location. The out-of-plane disturbance is capable of exciting the vibration modes of the structure when the actuator is strategically positioned on the membrane. Piezoelectric patches are most effective at strain anti-nodes, where the strain is high in the direction of the actuator. This is different from a traditional shaker modal test, where the shaker is most effective at displacement anti-nodes. Many actuator locations were tested to determine how to excite various modes of the membrane. The various actuator patch locations, shown in Figure 3, included excitation near the corners as well as within the body of the membrane.

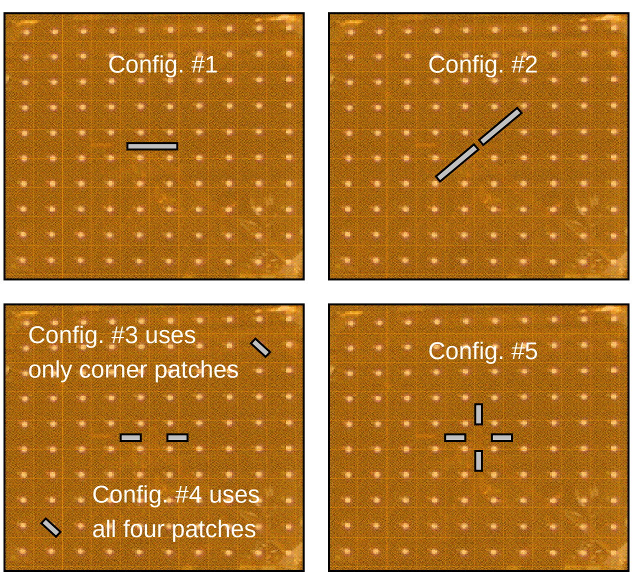

Figure 3: Actuator Configurations

2.5 Vibration Measurement Method

A Polytec PSV-300-H scanning laser vibrometer system is used to measure vibration of the test article. To provide more accurate measurements, 100 retro-reflective dots are adhered to the membrane in a grid pattern at even spacing of 101.6 mm (4 in) to allow for increased reflection of the laser beam to the laser vibrometer. The Polytec software is used to view frequency response functions (FRF's) and operating deflection mode shapes.

2.6 Test Description

All tests are performed with the membrane at a 20 N (4.6 lbf) tension level. Also, all tests apply a periodic chirp input signal with a bandwidth of 0 to 30 Hz to the actuators. The periodic chirp signal from the signal generator is used as the reference for the FRF calculations. To actuate the piezoelectric patches, the signal is amplified by 200 volts-per-volt with a Trek amplifier (Model PZD700) to produce a maximum input voltage of 1400 volts peak-to-peak (±700 volts). The FRF's are computed using 10 ensemble averages and a 256 Hz sample rate. The duration of each test is approximately 80 minutes to acquire all 100 FRF's. All of the vibration measurements in this report were made at ambient temperature and pressure conditions inside the high bay of the Structural Dynamics Laboratory located at the NASA Langley Research Center.

3. DISCUSSION OF TEST RESULTS

As with any modal test, accurate positioning of the actuators was found to be crucial for obtaining high quality modal data. A pretest finite element model was used to help evaluate high strain areas at each resonance, and modal test results were reviewed to locate the mode shape anti-nodes to determine good actuator locations. Few tests were able to excite all of the first five dominant modes well. The results from testing the membrane with various actuator configurations are discussed below.

3.1 One Long PVDF at Center Location

Figure 4 shows the coherence and mode shapes for the first five dominant modes excited using a single large PVDF actuator positioned at the center of the membrane. The coherence measurement indicates the degree of correlation between the input signal and the response signals. The coherence is used to assess the quality of the mode shapes obtained at resonance, with values

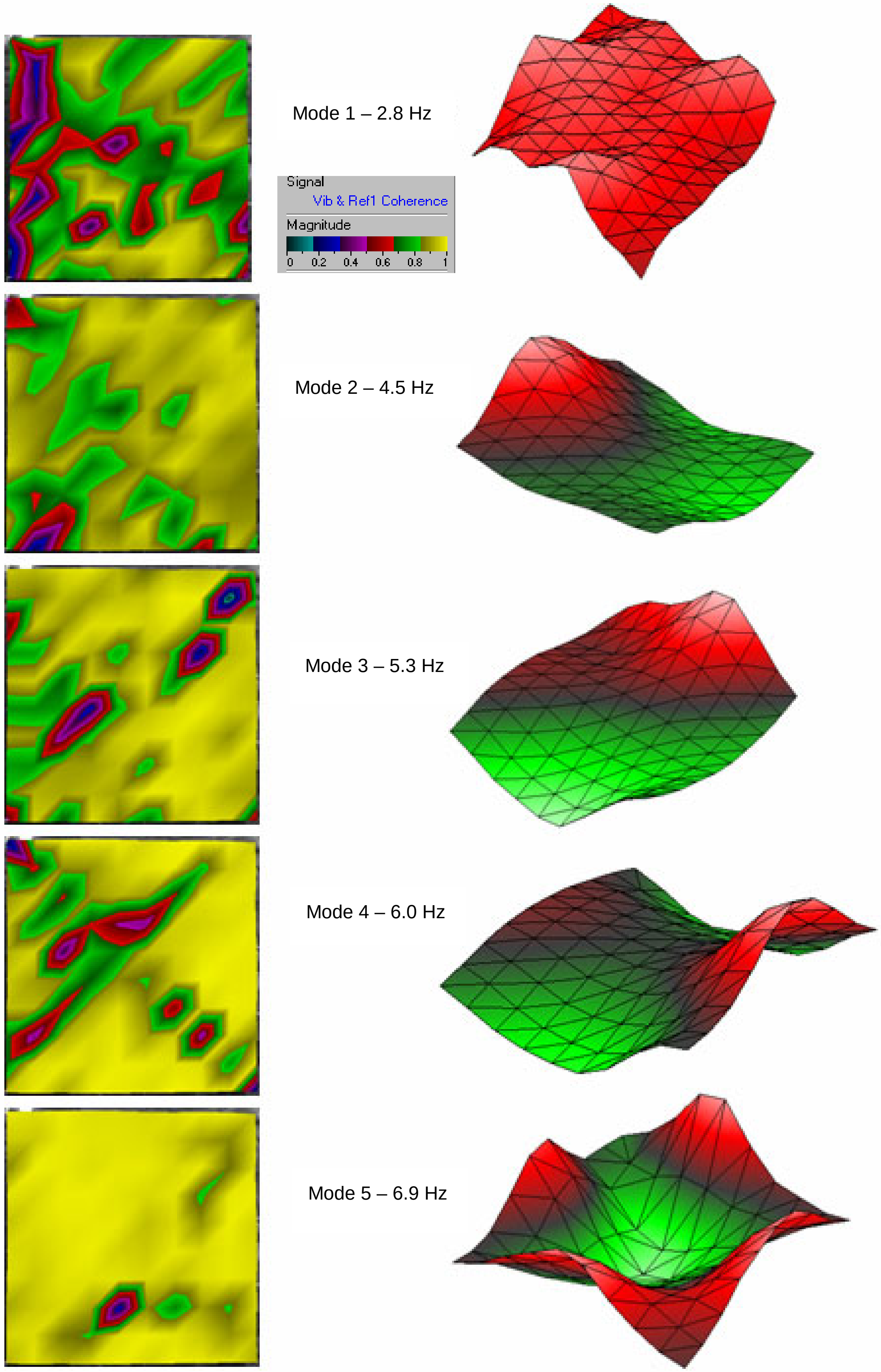

Figure 4: Coherence and Mode Shapes Obtained from Actuator Configuration #1

above 0.9 (light shade) over a large portion of the membrane surface considered to be good. The coherence plot, on the left side of Figure 4, shows how the coherence value changes across the surface of the membrane with the lightest shade being a high value above 0.9 and the darker shades decreasing in approximately 0.2 increments. These coherence plots show that four of the five modes are excited well with high coherence values and smooth symmetric mode shapes. The few low coherence values occur near node lines (locations with low motion), where the signal-to-noise ratio is poor and low coherence is acceptable.

The first mode at 2.8 Hz is poorly excited, as can be seen by the low coherence values along the left edge and over large portions within the body of the membrane. As a result, the mode shape for this mode is erratic and un-symmetric. This mode was rather difficult to excite for the majority of the tests performed on the membrane, regardless of excitation location. One reason for this is due to the fact that the mode is easily excited by ambient air effects in the lab, as shown by the frequency response in Figure 5. The figure shows the actuator did not excite the first mode much better than that obtained by ambient noise.

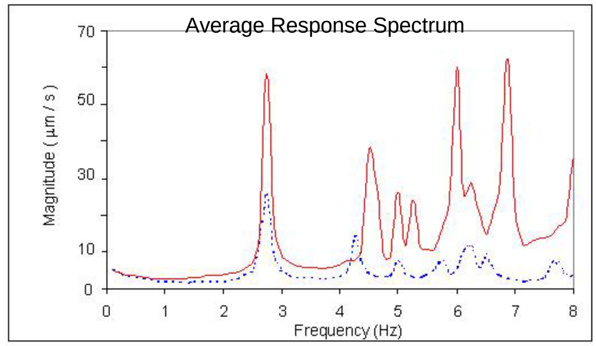

Figure 5: Config. #1 (Solid) vs. Ambient Noise (Dashed)

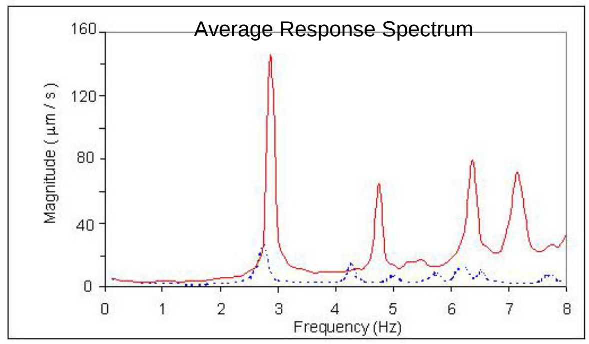

Figure 6: Config. #2 (Solid) vs. Ambient Noise (Dashed)

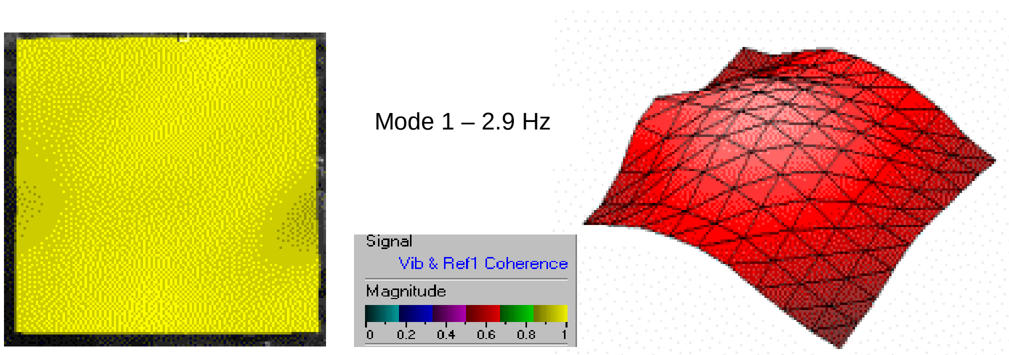

Figure 7: Coherence and Mode Shape Obtained from Actuator Configuration #2

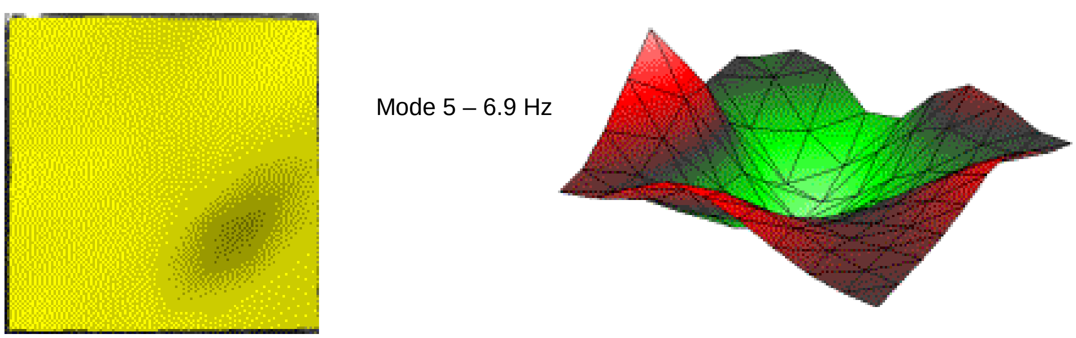

Figure 8: Coherence and Mode Shape Obtained from Actuator Configuration #3

3.2 Two Long PVDF's along Diagonal

Improved excitation of the first mode is obtained by using two long PVDF actuators located along a diagonal of the membrane at its center, as illustrated in Figure 3 (Configuration #2). Figures 6 and 7 show a significant improvement in frequency response, coherence, and mode shape.

3.3 Two Small MFC's at Opposite Corner Locations

Some attempts were made at exciting various modes with multiple actuators activated in-phase using the same input voltage periodic chirp signal. Configuration #3 (see Figure 3) excited mode 5 well by driving two small MFC actuators at opposite corners of the membrane. The mode shape and coherence is shown in Figure 8.

3.4 Four Small MFC's (2 at Center, 2 at Corners)

Two MFC actuators were added to the center and excited in-phase with the two corner actuators discussed for configuration #3, in an attempt to excite the other dominant modes (see configuration #4, Figure 3). However, the center actuators just distorted the mode shape for mode 5. Better control over which actuators are active at various frequencies may produce improved results.

3.5 Four Short Patches at Center (MFC versus PVDF)

Actuator configuration #5, shown in Figure 3, is used to evaluate the performance of the short PVDF and MFC patches. The MFC configuration did not excite mode 4 as well as the other modes. This may be due to the fact that this mode does not have a mode shape that is symmetric about the center of the membrane. Since the actuators are driven in-phase, they have a tendency to excite the mode shapes that are symmetric about the center of the membrane. Modes 2 and 3 are not symmetric about the center either, but they have a node line along one axis. Similar results are obtained with the short PVDF actuators, which is significant because they have much lower strain capability than the MFC's and a closer impedance match with the membrane.

4. CONCLUSIONS

Surface-bonded piezoelectric patches of different sizes were used to perform modal tests on a thin pre-tensioned membrane using various excitation locations. It was shown that surface-bonded piezoelectric patches provide adequate excitation energy to obtain modal frequencies and mode shapes on thin pre-tensioned flat membranes. However, good mode shapes were difficult to obtain and highly dependant on selecting a suitable location to properly excite the desired modes. It is believed that further work investigating optimum multi-point excitation locations and selectively controlling the energy input to each individual actuator over various frequency bandwidths will provide better results.

5. ACKNOWLEDGEMENTS

The authors would like to thank Dr. Keats Wilkie of NASA Langley for helpful discussions and for providing the MFC's.

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1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE February 2003	3. REPORT TYPE AND DATES COVERED Technical Memorandum	
4. TITLE AND SUBTITLE Membrane Vibration Tests Using Surface-Bonded Piezoelectric Patch Actuation			5. FUNDING NUMBERS WU- 755-06-00-21
6. AUTHOR(S) James L. Gaspar and Richard S. Pappa			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) NASA Langley Research Center Hampton, VA 23681-2199			8. PERFORMING ORGANIZATION REPORT NUMBER L-18261
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001			10. SPONSORING/MONITORING AGENCY REPORT NUMBER NASA/TM-2003-212150
11. SUPPLEMENTARY NOTES Presented at the 21st International Modal Analysis Conference (IMAC); Kissimmee, Florida; February 3-6, 2003.			
12a. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified-Unlimited Subject Category 39 Distribution: Standard Availability: NASA CASI (301) 621-0390			12b. DISTRIBUTION CODE
13. ABSTRACT (*Maximum 200 words*) This paper describes the status of on-going work at the NASA Langley Research Center to measure the dynamics of thin membranes. The test article is a one-meter square pre-tensioned Kapton membrane that incorporates small surface-bonded piezoelectric patches strategically positioned to excite many modes. It is shown that PVDF (polyvinylidene fluoride) and MFC (macro fiber composite) piezoelectric patch actuators provide adequate excitation energy to obtain modal frequencies and mode shapes. Results from modal tests performed on the membrane using piezoelectric patches of different sizes and positions are discussed.			
14. SUBJECT TERMS Membrane vibration; Scanning laser vibrometer; Gossamer spacecraft dynamics; Kapton membranes; Structural dynamics testing; Experimental modal analysis			15. NUMBER OF PAGES 12 16. PRICE CODE
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