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DYNAMIC TESTING OF A SUBSCALE SUNSHIELD FOR THE NEXT GENERATION SPACE TELESCOPE (NGST)

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ABSTRACT

The government 'yardstick' concept of the NGST sunshield is a lightweight, flexible structure consisting of multiple layers of pretensioned, thin-film membranes supported by deployable booms. The structural dynamic behavior of the sunshield must be well understood in order to predict its influence on observatory performance. Ground tests were carried out in a vacuum environment to characterize the structural dynamic behavior of a one-tenth scale model of the sunshield. Results from the tests will be used to validate analytical modeling techniques that can be used in conjunction with scaling laws to predict the performance of the full-sized structure. This paper summarizes the ground tests and presents representative results for the dynamic behavior of the sunshield.

INTRODUCTION

A conceptual design of the Next Generation Space Telescope (NGST), referred to as the 'yardstick' concept, was developed by the government to establish a reference design for the mission and identify areas in need of technology development. This concept utilizes a deployable sunshield to passively cool its optics and detectors. Large, thin-film membrane structures such as the 'yardstick' NGST sunshield represent a challenging new concept in gossamer space structures. The structural behavior of the sunshield must be well understood in order to ascertain its effect on the systems level performance of the observatory. Structural modeling and analysis techniques must accurately predict significant sunshield modes to ensure that they will not impair telescope performance. Structural modeling of thin-film membrane structures is a challenging aspect of sunshield technology development and analytical models need to be validated through correlation with test results to ensure their reliability. However, ground-based dynamic testing of full-scale sunshield structures may prove to be impractical because the structures are designed for operation in space and the presence of a gravity field alters the response of the system. An alternative approach is to test sub-scale models that are dynamically similar to the full-scale structure.

In order to validate the government sunshield concept and reduce risks, a flight experiment of a sub-scale NGST sunshield was implemented in the NGST technology roadmap: the Inflatable Sunshield In Space (ISIS) flight experiment.[1-3] The objective of the Space Shuttle based ISIS flight experiment was to characterize the structural dynamic behavior of a one-third scale NGST sunshield, correlate analytical models with test results, and demonstrate an inflatable deployment system. The ISIS experiment was cancelled in August 2000; however, an important element of the ISIS project that continues is the development and validation of analytical modeling techniques for predicting sunshield structural dynamic behavior.[4] There are two key elements to this work: (1) development and validation of advanced analytical techniques for modeling sunshield structural behavior and (2) ground testing of a one-tenth scale model NGST sunshield to provide data for model validation. This paper describes the results of a series of ground tests performed to characterize the dynamic behavior of the one-tenth scale model NGST sunshield.

TEST OBJECTIVES

The main objectives of the one-tenth scale sunshield ground dynamic tests were: (1) to gather data characterizing the dynamic behavior of a sub-scale model of the NGST sunshield for correlation with analytical models and (2) to validate dynamic test plans for the ISIS flight experiment. The specific objectives of the testing and their corresponding requirements are as follows: The first objective is to characterize the dynamic behavior of the sunshield under vacuum environment, which can be derived as follows: (a) identify natural frequencies, (b) characterize structural damping, and (c) capture mode shapes. The second objective is to simulate ISIS on-orbit testing in order to verify that the excitation, instrumentation, and data acquisition and processing techniques are adequate to meet mission objectives. The derived requirements associated with this objective are: (a) to implement similar instrumentation to the flight experiment (sensor types, number of sensors, locations), (b) to subject the test article to impulsive base excitation at scaled shuttle acceleration levels, (c) to utilize a ISIS-like data acquisition system and procedures, and (d) to process the results as planned for ISIS post-mission data analysis. The third objective is to verify the linearity of the system by subjecting the test article to excitation at different levels. Finally, the fourth objective is to characterize the influence of gravity by testing the sunshield in two different orientations using identical test procedures

TEST ARTICLE

The test article is a one-tenth-scale model of the NGST sunshield yardstick design. It was scaled down from the full-scale concept using constant thickness scaling laws.[5] The test article was designed and manufactured by L'Garde, Inc. under contract to NASA JPL. The main components of the test article are: a central mounting block, four support tubes with their corresponding tip hardware, and four membranes. Figure 1 presents a schematic of the sunshield test article which is 3.4 m long by 1.52 m wide by 0.1 m thick and has an overall mass of 4.1 kg.

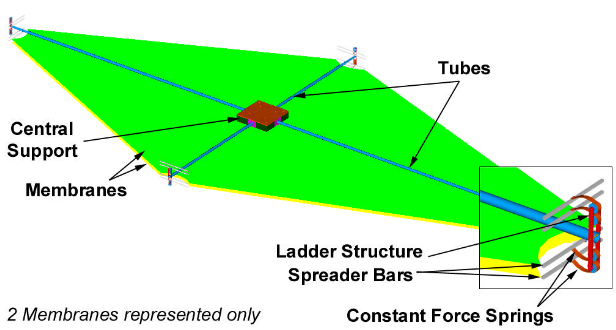


Figure 1 – One-tenth scale model NGST sunshield test article.

The central support is a rigid aluminum block from which the support tubes are cantilevered. The support tubes are circular cross-section aluminum tubes with an outside diameter of 0.0159 m (0.625 in.) and a wall thickness of 0.00165 m (0.065 in.). The tube tip hardware consists of a ladder structure, constant force springs (CFS), and an interface plug to attach the ladder structure and accelerometer to the tip of the tube. The purpose of the ladder structure is to maintain a constant distance between the membrane layers. The membranes are clamped at their root to the central block between thin aluminum plates that also maintain a constant spacing between the layers. The membranes are attached at their corners to CFS via a spreader bar, and the CFS are in turn mounted to the ladder structure. The CFS apply a constant preload of 1.425 N (0.32 lbs) at the corners of each of the membrane layers. There are four membrane layers, two on each side of the tubes, each consisting of a 13 micron (0.0005 in.) thick Kapton® film. The outer side of the membranes has a reflective gold coating, while the inner side is coated with vapor deposited aluminum (VDA).

TEST SETUP

This section describes the test setup, Fig. 2, for the dynamic tests, including: the test stand, excitation system, and instrumentation.

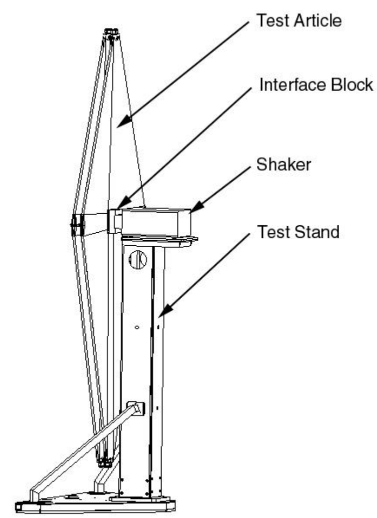


Figure 2 – Schematic of setup for ground tests.

TEST STAND

A test stand, Fig. 3, was designed and fabricated for supporting the test article during testing. It was designed to be a stand-alone structure that can be used in a lab or integrated into a thermal vacuum chamber. The test stand is a stiff framework of welded aluminum members composed of the following four sub-assemblies: base plate, column, support legs, and platform. The test stand has a footprint of 1.73 m by 0.76 m (68 in. by 30 in.) with a height of approximately 2 m. The column supports the test article at a suitable location, and the support legs provide additional stiffness for the column. The excitation system (shaker) is located on the platform at the top of the column. The test article cantilevered off the shaker armature in a vertical orientation via an interface block that attaches to the sunshield central support. The sunshield can be mounted on the test stand in two configurations: long side down and short side down. The sunshield is in the long side down orientation in Fig. 2. The center of gravity of the test stand is located approximately on the front face of the column at the height of the support leg attachment points. The total mass of the stand (excluding shaker and test article) is 238 kg (525 lbs). The stand was designed such that its first fundamental frequency was above the frequency range of interest for the sunshield test article (0-10 Hz) to avoid any dynamic coupling between the stand and test article. The analytical model of the stand predicted a first bending mode of the column at about 20 Hz. In the laboratory, the stand was sitting on the floor with 135 kg (300 lbs) of dummy weight on the base plate, whereas in the vacuum chamber it was clamped to a set of deck plates. The measured frequency of the lowest mode of the test stand was approximately 16 Hz in the laboratory and 10.5 Hz in the vacuum chamber. The difference between the predicted and measured frequencies is attributed to the boundary conditions at the base of the stand. The model assumes a fixed base; however, the stand could not be rigidly fixed at the base in either the laboratory or the vacuum chamber. In particular, the compliance of the deck plates in the vacuum chamber significantly reduced the first mode frequency of the stand; however, this frequency was still above the 0 – 10 Hz frequency range of interest for the sunshield test article.

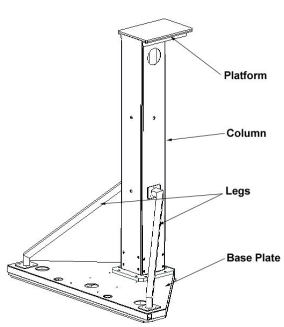


Figure 3 – Schematic of test stand.

EXCITATION SYSTEM

The excitation system consists of a shaker and its associated amplifier and input signal source. The shaker is an ELECTRO-SEIS® long stroke shaker manufactured by APS Dynamics (Carlisbad, CA). This shaker is capable of generating low frequency excitation and long duration impulses (shocks) due to its long stroke capability. The shaker is mounted on the platform at the top of the test stand, and the test article is then mounted to an interface block that is attached to the shaker armature. The shaker input signal was provided by three different systems during the testing: (1) an LMS VXI data acquisition system for random excitation tests, (2) an Ometron VPI 4000 laser vibrometer system for sine dwell tests, and (3) a Spectral Dynamics 2550 vibration controller for the impulse tests. Several materials in the shaker were replaced during manufacturing to avoid contamination problems during vacuum operations. The performance of the shaker under vacuum conditions was evaluated prior to sunshield testing to verify that: (1) outgassing was within acceptable limitations for the vacuum chamber and (2) the shaker would not overheat in the absence of convective cooling during extended vacuum operations. The thermal performance of the shaker was monitored using thermocouples mounted on the casing and armature throughout vacuum testing to ensure that temperatures remained within operational limits.

INSTRUMENTATION

The instrumentation suite for the tests consisted of both conventional and advanced non-contact instrumentation. The conventional instrumentation consisted of twelve tri-axis accelerometers to measure the response at the tips of the support tubes, at the drive point, and at key locations on the test stand; and, five single-axis force gages to measure the excitation force. The accelerometers used were Kistler low impedance Piezobeam Model 8690C triaxial accelerometers. Kistler Model 5148 Coupler/Power Supplies were used to condition the accelerometer signals. The load cells were Kistler high impedance Model 9251A force transducers. Kistler Model 5148 Coupler/Power Supplies in combination with inline charge converters were used to condition the force transducer signals. The test article was instrumented (see Fig. 4) with a total of five tri-axis accelerometers (four located at the tips of the tubes and one on the interface block). Four single-axis load cells were located between the central block and the interface block. Another single-axis load cell was located between the interface block and the shaker armature that was used as a reference for frequency response function computations. The test stand was instrumented (see Fig. 4) with seven tri-axis accelerometers to characterize stand frequencies and the associated mode shapes. Two accelerometers were located at opposite corners of the platform at the top of the stand, two accelerometers were mounted on the column (at mid-length and at the base), and the three accelerometers were located on the base plate (one at each corner of the triangle and one in between).

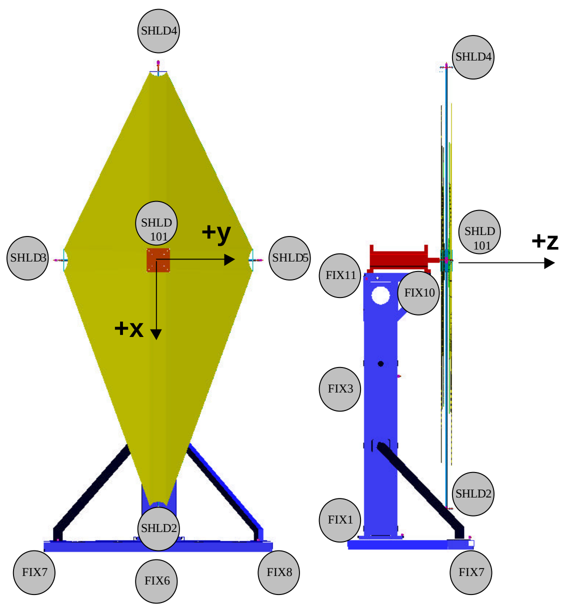


Figure 4 – Locations of accelerometers on test article and test stand.

An Ometron VPI 4000 scanning laser vibrometer was used to measure the velocity of the outer membrane layer at different locations. The laser vibrometer was operated in two different modes: (1) as a single point measurement device while the sunshield was subject to random and impulse excitation and (2) as a scanning system during sine dwell excitation at specific frequencies. Note that a portion of the long side of the sunshield was out of the laser field of view due to an obstruction by the vacuum chamber shroud in the short side down orientation. In the case where the laser vibrometer was used as a single point-measuring device, the outer membrane layer was virtually meshed with approximately 40 grid points, Fig. 5, that were targeted one by one. This type of measurement was time consuming due to the need to re-run the test for each laser target. The use of the laser in this mode allows for the calculation of frequency response functions for the outer membrane layer over the entire frequency range of interest, whereas the sine dwell tests only provide the velocity contours/mode shapes for a single specific frequency. For impulse tests, each test was repeated twice in order to target the laser head at two points on the outer membrane layer (long and short sides).

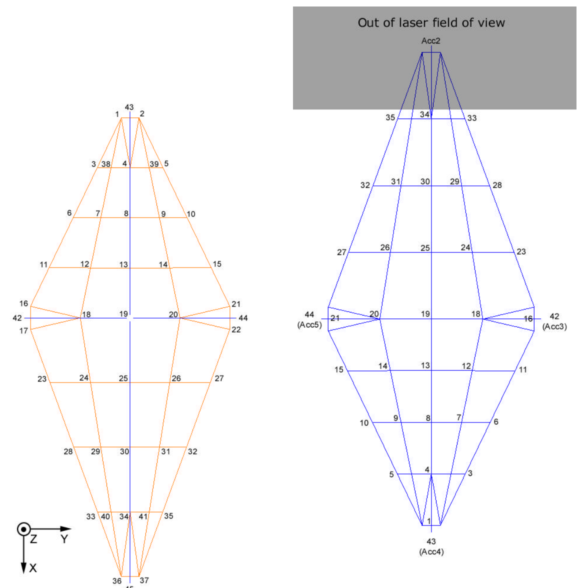


Figure 5 - Laser target locations on outer membrane layer.

TEST PROCEDURES

This section describes the procedures for the ground tests. Prior to the vacuum environment testing, an extensive series of tests were performed in the laboratory. The objectives of these tests were: (1) to characterize the dynamic behavior of the test stand and to verify that its fundamental natural frequency was effectively out of the frequency range of interest for the sunshield test article, (2) to gain experience using the laser vibrometer system on a simple structure having frequencies close to the predicted sunshield modes, (3) to characterize the behavior of a 'tubes-only' sunshield test article, (4) to identify excitation levels and perform a dry run of the planned vacuum chamber tests using a single layer membrane configuration, and (5) to gather a set of data comparable to in-vacuum measurements for air influence characterization. The time spent for these tests was valuable in that it allowed the following to be determined before vacuum chamber testing:

- The test stand modes were above 0-10 Hz frequency range of interest for the sunshield.
- The shaker armature suspension has a rigid body mode near 0.5 Hz.
- The reflectivity of the coated membranes does not affect laser measurements.
- Frequency response functions processed using the laser system and accelerometers identified identical modes.
- Measurements showed that the measured frequencies of the support tubes matched predicted values.

The following sections describe the procedures used during dynamic testing in the vacuum chamber. The test article was subjected to three different types of tests: random, sine dwell and impulse. Each of these tests was performed with the sunshield in both the short and long side down orientations. Prior to the start of testing, a characterization of the background acceleration level (noise) in the vacuum chamber was performed. The effective background noise level was found to be approximately 1 to 2 mg rms.

RANDOM EXCITATION TESTS

Random excitation tests were performed to measure frequency response functions from which natural frequencies, damping coefficients, and mode shapes for the system can be identified. The tests were completed at an excitation level of 10 mg rms in the z-direction measured at the interface block. The following processing parameters were set and maintained for each test run:

- Frequency range: 0-32 Hz
- Frequency resolution: 0.0156 Hz
- Number of averages: 15
- Overlap: 50%

During testing, the data acquisition system processed each channel to calculate its respective frequency response function, coherence, auto power spectrum, and cross power spectrum. The reference channel used to generate FRF's was the single load cell located between the interface block and the shaker armature (drive point).

SINE DWELL TESTS

Fine-scale mode shape recovery for the outer membrane layer was completed using the laser vibrometer in scanning mode with the test article under constant frequency sine excitation. The frequencies at which the sine dwell tests were performed were determined using preliminary results from the random excitation tests. The laser system has a signal source that was set to generate a sine signal at a specified frequency that was used as the input to the shaker amplifier. The result was single frequency sinusoidal acceleration of the test article. The laser vibrometer system has a feature called a "lock-in amplifier" that is used for the sine dwell tests. The lock-in amplifier is essentially a tracking filter that uses a reference signal to determine frequency and then determines the amplitude and phase of the response velocity relative to the reference signal. Typically the reference signal would be the force gage signal, but for these tests the excitation level was low resulting in a force gage output signal that was too low to work with the lock-in amplifier. For these tests, the laser system source signal was used as the reference. While using the lock-in amplifier, the laser vibrometer sensor head can be used to scan across the test item using a user-defined number of points. When scanning the test item, the laser briefly dwells at each point for a user-selected time. The velocity magnitude and phase information for each point is then saved onto disk. Post processing of this data provides velocity contours that can be interpreted as mode shapes. The excitation level used for all the sine dwell tests was 10 mg rms (~20 mg peak) and was monitored using the interface block accelerometer and an oscilloscope/volt meter. Only the laser vibrometer was used for these tests, no other data was recorded. In the long side down orientation 546 points were scanned, whereas 771 points were scanned for the short side down configuration. The total data acquisition time was about 10 minutes for a 1 second measurement dwell time at each individual point and doubled (~20 min) for the 2 second measurement dwell time used at lower frequencies (< 2 Hz).

IMPULSE EXCITATION TESTS

Impulse excitation tests were performed to validate the instrumentation and excitation methods planned for the ISIS flight experiment. The sunshield was subjected to a series of half-sine impulses at different acceleration levels using several pulse durations. A Spectral Dynamics 2550 controller running a classical shock program was used to generate a half-sine impulse at a specified acceleration level for a period of time. The conventional sensors measured the free-decay acceleration and force response of both the test stand and the sunshield. The laser vibrometer system was used as a single point measurement device and each test was run twice to gather velocity data at two different membrane locations: (1) on the long side and (2) on the short side. The data acquisition system was setup to acquire 10 minutes of time histories. During this 10 minutes, the impulse was repeated approximately every 60 seconds. This resulted in 10 impulses (and the associated free decays) being captured during each 10 minute time history. This provided 10 averages for the FRF processing. The DAQ system was setup with the following parameters during testing:

- Frequency range: 0-32 Hz
- Sampling frequency: 64 Hz

The excitation levels were derived from anticipated NGST and Space Shuttle acceleration levels. Four levels were defined prior to the start of testing: 0.5, 5, 50, and 100 mg. However, the background noise environment level of 1 - 2 mg drove the decision to eliminate the 0.5 and 5 mg levels because they were too close to the noise level. The impulse durations were initially defined using the analogy of an undamped single degree of freedom system subjected to rectangular pulse loading. The maximum theoretical amplification for such a system occurs for pulse durations greater than or equal to one-half the natural period of vibration of the system. Thus, the impulse durations for the tests were chosen such that the period of the half-sine pulse was greater than or equal to one-half the period of the lowest frequency mode of interest. For example, a 500 ms pulse will provide maximum amplification of all the modes above 2 Hz, whereas a 25 ms pulse will excite modes above 40 Hz. Pulse durations were defined prior to starting the test ranging from 25 ms to 500 ms; however, shaker stroke, and controller capabilities limited the selection of this parameter. It is impossible to generate a 'pure' half-sine or rectangular impulse waveforms using a shaker due to the physical operating constraints of the system. There is a need for some pre and/or post compensation of the impulse waveform. Three control modes were available with the shock controller used in the tests: (1) pre-control only, (2) post-control only, and (3) pre and post control (Figure 6). Impulse durations used to excite the sunshield were a compromise between stroke length, acceleration level, pulse duration, and control mode. Table 1 summarizes the input levels and pulse durations for each of the impulse tests.

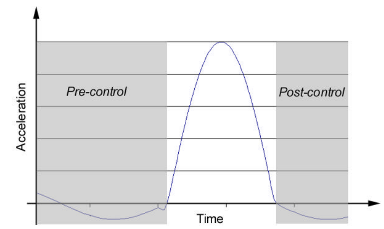


Figure 6 - Impulse acceleration profile.

Test	Acceleration level	Impulse duration	Control
1	50mg	25ms	Pre only
2	50mg	180ms	Pre only
3	50mg	350ms	Pre & Post
4	100mg	25ms	Pre only
5	100mg	140ms	Pre only
6	100mg	220ms	Pre & post

Table 1 – Summary of impulse excitation tests.

TEST RESULTS

A summary of the results from the ground tests is presented in this section. A complete description of the test results is presented in Ref. 6. The test results are presented here in terms of the test objectives: (1) characterization of sunshield dynamics, (2) evaluation of the test plan for the ISIS flight experiment, (3) characterization of system linearity, and (4) evaluation of the influence of gravity on the dynamic response.

SUNSHIELD DYNAMIC CHARACTERIZATION

The primary objective of the testing was to determine the dynamic characteristics (natural frequencies, damping, and mode shapes) of the sunshield. A summary of the natural frequencies and damping values for the sunshield modes identified during testing are presented in Tables 2-3. The modal parameters for the sunshield were determined by curve fitting performed with I-DEAS modal analysis software using combined accelerometer and laser vibrometer data sets from the random excitation tests.

A total of eight sunshield modes where identified in the 0 - 10 Hz frequency range for the short side down orientation at a random excitation level of 10 mg rms (Table 2). Additionally, one mode associated with the shaker (0.4 Hz) and one mode associated with the test stand (10.5 Hz) were identified.

Mode	Short Side Down Orientation	
	Frequency (Hz)	*Damping (%)*
1	1.609	*8.8*
2	1.841	*5.6*
3	2.426	*10.2*
4	2.998	*4.8*
5	3.483	*5.2*
6	4.109	*6.2*
7	5.074	*6.4*
8	5.962	*3.2*

Table 2 – Summary of sunshield natural frequencies and damping values for the short side down orientation.

The mode shapes obtained from the analysis of the test results were examined to identify the form of each mode. A complete listing of the mode shape coefficients is provided in Ref. 6. Modes 1-2 are associated with a 'flapping' of the outer edges of the membranes. The edges move in-phase in mode 1 and out-of-phase in mode 2. Mode 3 primarily involves the edges of the long side of the membranes. The peak response in modes 4 and 5 occurs in the long tube and the long side of the membranes. In mode 4, the center of the long side of the membranes is in-phase with the long tube, while the edges are out-of-phase. In mode 5, the center of the long side of the membranes is out-of-phase with the long tube, while the edges are in-phase. Mode 6 involves the long and short sides of the membranes moving out-of-phase with the long and medium tubes. Modes 7-8 are associated with the medium tube and the short side of the membranes. In mode 7, the center of the short side of the membranes is in-phase with the medium tube, while the edges are out-of-phase. In mode 8, the center of the short side of the membranes is out-of-phase with the medium tube, while the edges are in-phase. Examination of Table 2 shows that the sunshield modes have damping values in the range of 3 - 10%. Sunshield modes associated primarily with a large response at the membranes typically exhibit higher damping values than modes associated with the support tubes.

Seven sunshield modes where identified in the 0 - 10 Hz frequency range for the long side down orientation (Table 3). As with the short side down tests, additional modes associated with the shaker (0.4 Hz) and test stand (10.5 Hz) were identified at the upper and lower bounds of the frequency range.

Mode	Long Side Down Orientation	
	Frequency (Hz)	*Damping (%)*
1	1.462	*5.6*
2	2.319	*6.9*
3	2.714	*6.2*
4	3.395	*2.9*
5	4.093	*5.1*
6	4.501	*3.1*
7	5.477	*2.5*

Table 3 – Summary of sunshield natural frequencies and damping values for the long side down orientation.

The test-derived mode shapes were once again examined to identify the form of each mode. The peak response in mode 1 occurs in the long tube and the long side of the membranes with the center of the long side of the membranes moving in-phase with the long tube, while the edges are moving out-of-phase. Modes 2-3 are associated with a 'flapping' of the outer edges of the membranes. The edges move in-phase in mode 2 and out-of-phase in mode 3. The peak response in mode 4 occurs in the long tube and the long side of the membranes with the center of the long side of the membranes moving out-of-phase with the long tube, while the edges are in-phase. Mode 5 involves the long and short sides of the membranes moving out-of-phase with the long and medium tubes. Modes 6-7 are associated with the medium tube and the short side of the membranes. In mode 6, the center of the short side of the membranes is in-phase with the medium tube, while the edges are out-of-phase. In mode 7, the center of the short side of the membranes is out-of-phase with the medium tube, while the edges are in-phase.

The random excitation tests demonstrated that the dominant sunshield modes are associated with the fundamental bending modes of the long and medium length support tubes. The response of the system at these frequencies is significantly greater than at the frequencies associated with the membrane modes. There are several modes of the membranes in the 1 - 3 Hz frequency range. Some of these are believed to be associated with 'flapping' of slack regions along the outer edges of the membranes. Finite element analysis predicts the existence of several modes that involve all four membrane layers moving in phase and driving the support tubes. It remains unclear from the testing which of the measured modes correspond to these predictions since measurements were only obtained for the outer membrane layer. Note that these low frequency 'membrane modes' are readily observed in the laser vibrometer data, but are not as clearly identifiable in accelerometer data (i.e. they are uncoupled from the support structure response to a certain degree). Mode shapes for the outer membrane layer were successfully obtained at frequencies associated with the resonant modes of the system using two different methods. The first method used the laser vibrometer as a single point measurement device while the sunshield was subject to random excitation. The second method involved using the laser vibrometer in scanning mode with the test article under constant frequency sine excitation. Figure 7 presents representative sine dwell test results for two of the dominant sunshield modes for both the short and long side down configurations. The first velocity contour presented in Fig. 7 is associated with the first bending mode of the long tube at approximately 3.5 Hz. The velocity contour shows that the center of the long side of the outer membrane layer is out-of-phase with the edges. The second mode is associated with the first bending mode of the medium tube. In this mode, the center of the short side of the membrane is out-of-phase with the edges. In general, the sine dwell tests provided comparable results to the single point acquisition tests, but at greater spatial resolution.

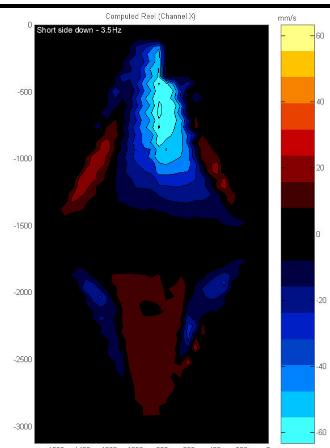
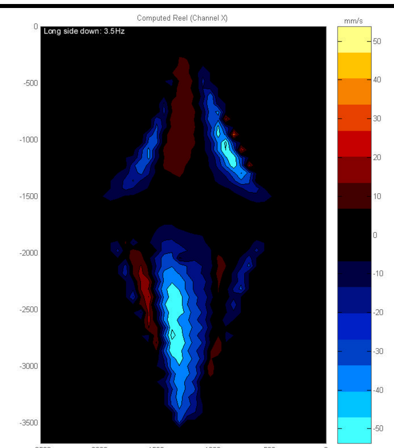
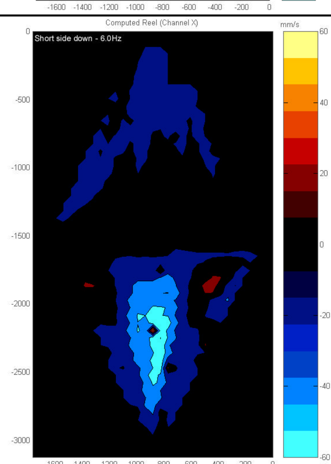
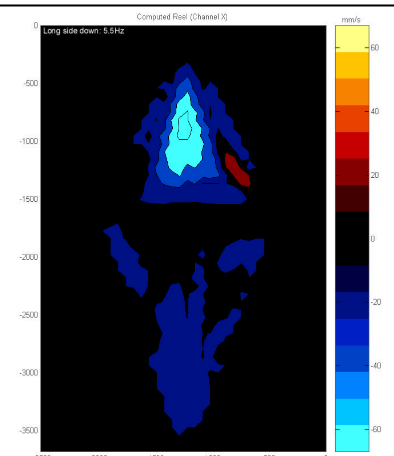
Description of Mode	Short Side Down Orientation	Long Side Down Orientation
Mode involving long tube and long side of membranes Frequency: Short side down = 3.5 Hz Long side down = 3.5 Hz		
Mode involving medium tube and short side of membranes Frequency: Short side down = 6.0 Hz Long side down = 5.5 Hz		

Figure 7 – Representative results from sine dwell tests. Phase corrected velocity contours for: (a) long tube mode and (b) medium tube mode.

EVALUATION OF ISIS TEST PLAN

The verification of the excitation method, instrumentation, and data acquisition and processing techniques proposed for use on the ISIS flight experiment was the second objective of the ground tests. Results from the random and impulse excitation tests are compared here for the short side down orientation of the sunshield. Figures 8-11 present plots of the measured frequency response functions (FRF's) for the out-of-plane (z-direction) response of the test article. Figures 8 and 9 show the measured FRF's for the sunshield support structure (tubes and central block). Figures 10-11 present the measured FRF's from measurement points on the short (SS12) and long (SS24) sides of the outer membrane layer. The reference channel for all of the FRF's is the force gage at the test article/shaker interface.

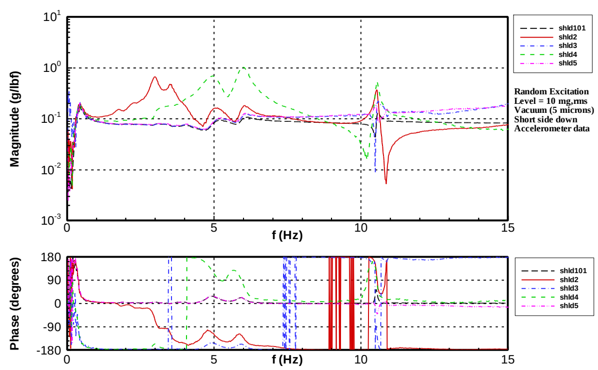


Figure 8 - Frequency response functions for support tubes from a random excitation test (10 mg rms) with the sunshield in the short side down orientation.

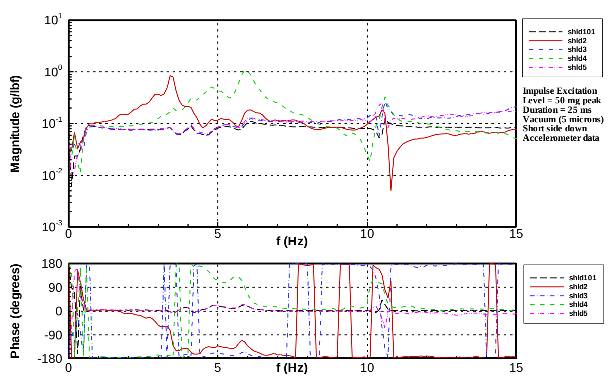


Figure 9 – Frequency response functions for support tubes from an impulse excitation test (100 mg peak/25 ms duration pulse) with the sunshield in the short side down orientation.

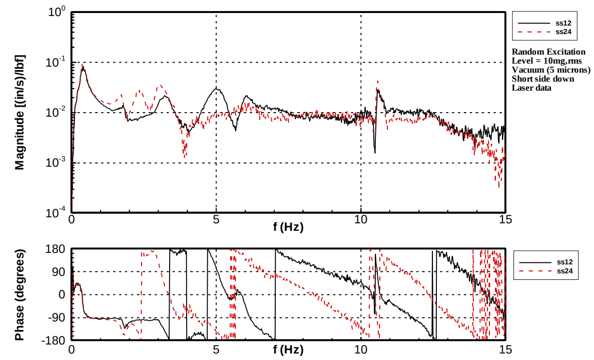


Figure 10 - Frequency response functions for membranes from a random excitation test (10 mg rms) with the sunshield in the short side down orientation.

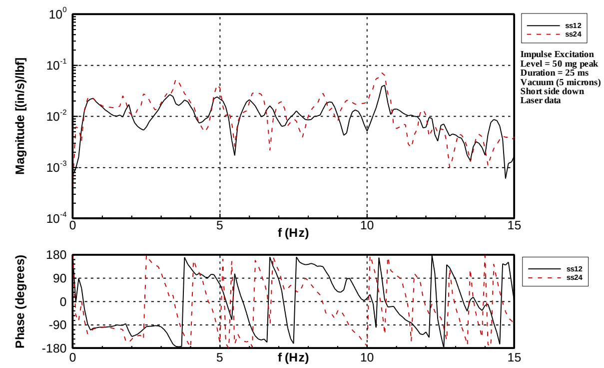


Figure 11 - Frequency response functions for membranes from an impulse excitation test (100 mg peak/25 ms duration pulse) with the sunshield in the short side down orientation.

With respect to the excitation method, results from the impulse excitation tests provided natural frequencies and damping values comparable to the results obtained from the random excitation tests. However, the impulse excitation tests provided only limited mode shape information due to the limited number of membrane measurements. An additional difficulty encountered during the impulse tests involved the generation of the impulse waveform. Due to limitations of the shaker and controller it was not possible to generate all of the long duration impulses desired. It was also discovered that the short duration impulses provided the best results (even though maximum amplification was not obtained for the low frequency modes) because the longer duration impulses required greater levels of pre and post control. This was because the motions imparted by the post control interfered with the recovery of the short duration free-decay response of the system. The instrumentation planned for the ISIS experiment consisted of accelerometers at the ends of the support booms and at the central container along with force transducers at the sunshield interface. The ground tests demonstrated that this instrumentation suite would provide sufficient results to characterize the support boom modes, but would not be sufficient to fully characterize the behavior of the membranes. The addition of a laser vibrometer or the use of some other non-contact measurement technique such as photogrammetry would be required to measure the response of the membranes. Additionally, the relatively high damping exhibited by the sunshield would limit the amount of transient response data that can be obtained prior to damping out of sunshield motions. The data acquisition system and data processing techniques for the ISIS flight experiment were not fully defined prior to the ground tests; however, the procedures used in this test series proved adequate. In general, these tests validated the approach planned for determining the dynamic characteristics of a 1/3rd scale NGST sunshield during the planned ISIS flight experiment.

CHARACTERIZATION OF SYSTEM LINEARITY

An assessment of the linearity of the sunshield dynamic response was obtained by exciting the sunshield with input accelerations ranging from 6.5 to 50 mg rms random excitation. The sunshield was in the long side down orientation for all of the tests. Table 4 summarizes the natural frequencies and damping values, ζ, obtained from the analysis of the results. Note that the analysis was performed using only data from the accelerometers due to the limited number of membrane measurements (only two points) obtained during the impulse tests. A total of 6 modes were identified including one shaker mode, four sunshield modes, and one test stand mode. The additional modes in the 1.5 – 3 Hz range associated with membranes are not seen in these results since they were derived purely from accelerometer data and do not include direct membrane measurements. Comparing the behavior of the sunshield over the range of excitation levels shows that frequencies and damping values are fairly consistent. Comparison of the measured frequency response functions for the support tubes and membranes (see Ref. 7) demonstrated that the magnitude of the response of the tubes is, in general, linear over the range considered. The response of membranes exhibits some nonlinearities. While the frequencies of the membrane modes are consistent over the range of excitation considered, the magnitude of the response differed significantly. These results are somewhat inconclusive due to the limited number of membrane measurements obtained.

EVALUATION OF THE INFLUENCE OF GRAVITY

The influence of gravity on the dynamic response of the sunshield was evaluated by comparing results from the short and long side down orientation tests. The results demonstrate that there is a significant influence on the behavior of the sunshield. Frequency shifts were observed in several of the important modes. The long tube mode at 3.5 Hz is consistent between the two cases. However, the medium tube modes occur at 5 / 6 Hz for the short side down orientation and 4.5/5.5 Hz for the long side down case. Additionally, the sunshield typically exhibited a higher magnitude response in the long side down orientation.

Mode	6.5 mg rms		10 mg rms		30 mg rms		50 mg rms	
	f (Hz)	*z (%)*	F (Hz)	*z (%)*	f (Hz)	*z (%)*	f (Hz)	*z (%)*
1	0.515	*10.8*	0.484	*19.5*	0.424	*10.0*	0.443	*20.0*
2	3.411	*2.3*	3.433	*2.8*	3.390	*3.9*	3.386	*3.8*
3	4.077	*2.7*	4.097	*2.8*	4.059	*4.0*	4.158	*8.1*
4	4.443	*3.1*	4.516	*3.2*	4.455	*7.1*	4.892	*3.1*
5	5.416	*2.2*	5.502	*2.5*	5.500	*3.5*	5.496	*4.2*
6	10.454	*0.6*	10.541	*0.4*	10.412	*0.4*	10.447	*0.3*

Table 4 – Comparison of frequencies and damping values, *z*, for long side down configuration from random excitation tests at 6.5, 10, 30, and 50 mg rms.

CONCLUSIONS

Dynamic testing of a one-tenth scale model NGST sunshield was completed to provide data for validation of analytical models. A brief summary of the tests is presented with respect to the four main objectives of the testing.

Objective 1: Dynamic Characterization

The dynamic characteristics (natural frequencies, damping values, and mode shapes) of the sunshield were obtained through testing performed in a vacuum environment. Mode shapes for the outer membrane layer were obtained from laser vibrometer measurements using two different methods: (1) random excitation with single point acquisition measurements from the laser vibrometer and (2) sine dwell excitation with the laser vibrometer operated in the scanning mode.

Objective 2: Validation of ISIS Test Plan

The impulse excitation tests provided results comparable to random excitation test results in terms of the natural frequencies, damping values, and course mode shapes for the system. The instrumentation suite proposed for use on the ISIS flight experiment would have provided minimally sufficient data for boom characterization, but would not have provided sufficient data to characterize membrane behavior without the use of photogrammetry or some other method of obtaining direct membrane measurements.

Objective 3: Characterization of System Linearity

An assessment of the linearity of the sunshield dynamic response was obtained by exciting the sunshield with input accelerations ranging from 6.5 to 50 mg rms. In general, the response of the support tubes is linear over the range considered. The response of membranes exhibits some nonlinearities. Additional tests are needed to further characterize the linearity of the system including a repeat of the current tests and new tests using alternate testing methods such as sine sweep excitation.

Objective 4: Evaluation of the Influence of Gravity

The evaluation of the influence of gravity on the behavior of the sunshield was the final objective of the ground tests. Comparison of results from tests completed with the test article in two different orientations with respect to gravity show that there is a significant influence on the dynamic response of the sunshield. This result highlights the importance of gravity effects on the dynamic performance of ultra-lightweight structures in a 1-g environment.

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