Initial Structural-Acoustic Modeling and Control Results for a Full-Scale Composite Payload Fairing for Acoustic Launch Load Alleviation

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ABSTRACT

Launch loads, both mechanical and acoustic, are the prime driver of spacecraft structural design. Passive approaches for acoustic attenuation are limited in their low frequency effectiveness by constraints on total fairing mass and payload volume constraints. Active control offers an attractive approach for low frequency acoustic noise attenuation inside the payload fairing. Smart materials such as piezoceramics can be exploited as actuators for structural-acoustic control. In one active approach, structural actuators are attached to the walls of the fairing and measurements from structural sensors and/or acoustic sensors are fed back to the actuators to reduce the transmission of acoustic energy into the inside of the payload fairing. In this paper, structural-acoustic modeling and test results for a full scale composite launch vehicle payload fairing are presented. These analytical and experimental results fall into three categories: structural modal analysis, acoustic modal analysis, and coupled structural-acoustic transmission analysis. The purpose of these analysis and experimental efforts is to provide data and validated models that will be used for active acoustic control of the payload fairing. In the second part of the paper, this closed-loop acoustic transmission reduction is implemented and measured on a full-scale composite payload fairing.

INTRODUCTION

The structural design of expendable launch vehicle (ELV) payloads is driven by the severity of the launch environment. The loads transmitted to the payload from the ELV in the first few minutes of flight are far more severe than any load that a payload experiences on orbit. Therefore, payloads are qualified by subjecting them to loads whose magnitude and frequency content are representative of the launch environment. A more severe environment increases the cost of placing the payload into orbit because it must be designed to withstand higher launch loads. Reduction of these loads offers several benefits to the spacecraft designer and manufacturer, such as smaller lifetime cost due to the ability to use more off-the-shelf components and extend mission lifetime by carrying fuel in place of structural mass; and enhanced spacecraft survivability through the reduction of flight qualification loads. Passive vibration isolation has made tremendous progress during the last several years in reducing the levels of transmitted mechanical loads from the launch vehicle through the payload adapter to the payload, with the transition to flight demonstration currently taking place. As vibration isolation gains widespread use, the emphasis will shift to attenuation of acoustic loads.

Acoustic loads are a major component of the launch environment for ELVs. Exterior sound pressure levels on an ELV can reach 150 dB depending on the vehicle and the launch configuration. The magnitude of the acoustic loads transmitted to the payload is a function of the external acoustic environment as well as the design of the payload fairing and its sound absorbing treatments. Several

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approaches, which can be broadly grouped into passive and active as shown in Figure 1, can be used to reduce acoustic launch loads. One could also consider two other approaches, such as modification of the disturbance environment and modification of the enclosed payload. The first of these would require changing the flight profile of the launch vehicle, which is not realistic. The second approach, is in fact, the approach that is currently followed, in which the payload is beefed up to survive the high launch loads. An additional constraint imposed on the payload is that for separation concerns, instrumentation of the payload with acoustic sensors must be ruled out. These constraints force us to focus all our acoustic alleviation efforts on the fairing, which is reflected in Figure 1.

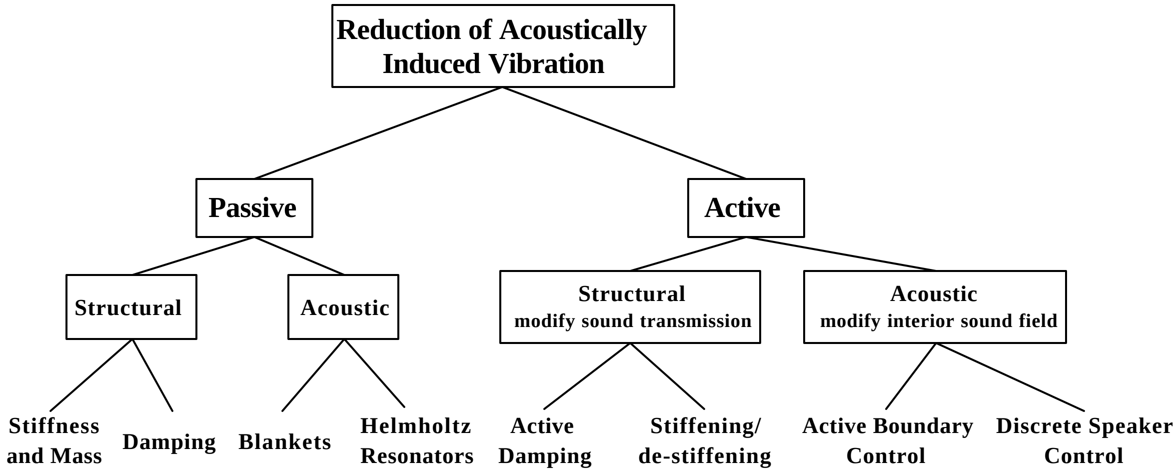

Figure 1. Acoustic Launch Load Alleviation Approaches

The trend toward composite payload fairings to reduce launch vehicle dry weight is having a detrimental effect on acoustic levels inside the payload fairing. This is because one of the most effective means for improving the passive acoustic transmission characteristics of structures is to simply add mass to the structure, which is counteractive to the weight reduction goal of composite fairings. Currently, the standard industry practice is to use passive acoustic blankets, which attenuate sound energy by trapping the energy in the blanket material and dissipating it as heat. Unfortunately, however, passive blankets are limited in their low-frequency effectiveness. This is due to the fact that for the blanket to be effective, its thickness must be a significant fraction of the wavelength of the sound wave for a given frequency. Thus, since acoustic wavelengths increase as frequency decreases, the only way to improve the lower frequency limit of the passive blanket is to make it thicker, which is undesirable because of the large mass and volume penalties that are imposed. Other passive approaches work by adding dissipation mechanisms to the enclosing structure or the acoustic cavity. Adding structural damping reduces the magnitude of vibration at the structural resonances which in turn reduces the acoustic field transmitted at those resonant frequencies. Helmholtz resonators, which are the acoustic equivalent to tuned vibration absorbers, are used to absorb acoustic energy at specific frequencies, typically the acoustic modal frequencies.

The motivation for active acoustic attenuation in payload fairings is the limited low frequency effectiveness of added mass and acoustic blankets. Added mass has limited effectiveness at low frequencies; its primary function is to increase the insertion loss of the fairing above its ring frequency. Acoustic blankets are less effective at low frequencies because the sound absorption is limited by the thickness of the blanket. Blankets are typically 2 to 4 inches thick, making them effective to approximately 300 to 400 Hz. Below those frequencies, the wavelength of sound is too long for sound waves to be trapped in the blankets and dissipated as heat. Added damping is effective only in those situations where the structural modes are well coupled to the interior cavity acoustic modes. Helmholtz resonators suffer similar drawbacks as passive blankets, such as a large mass penalty for targeting low frequency acoustic modes.

Active structural-acoustic control has the potential to overcome these limitations. Traditional methods, such as those discussed in the textbooks by Elliot, Nelson, and Fuller, have been applied to many problems in sound transmission and structural sound radiation (Nelson, and Elliot, 1993; Fuller, 1996). It has been applied to the fairing acoustic control problem by Ellis and Koshigoe (1994), Houston, *et al*, (1996), and Niezrecki and Cudney (1996). In Ellis and Koshigoe's work, adaptive feedforward control was used to reduce the sound transmission through a flexible plate into a rigid cavity. Houston, *et al*, numerically simulated 'active boundary control' techniques that changed the impedance of the fairing surface to reduce sound transmission. In their summary work, Niezrecki and Cudney assessed the feasibility of several active control techniques for the fairing acoustic problem.

The active control approaches can be broadly classed into two groups depending on whether the control objective emphasizes a structural metric or an acoustic metric. Two of the possible objectives of structural control utilizing structural actuators and sensors are to enhance the structural damping of the fairing or to modify the stiffness of the fairing structure. In acoustic control, the actuators can be either an acoustic speaker or structural actuators such as piezoelectric patches or proof-mass actuators and the sensors are a combination of structural and acoustic sensors. In active boundary control, the impedance properties of the wall are modified by feeding back structural and acoustic measurements to structural actuators to attenuate the acoustic transmission. In speaker control, acoustic speakers are used to reduce the acoustic field through feedback of acoustic sensors distributed throughout the cavity.

Each of the approaches in Figure 1 has its place in attenuating the acoustic loads experienced by a payload during launch. Indeed, because of the extreme complexity of the transmission problem and the difficulty of reducing the transmitted acoustic field, it is expected that a combination of these approaches will be required to achieve the desired reduced acoustic levels. The focus of the present work is to assess the feasibility of using distributed structural sensors and actuators for active acoustic control in payload fairings. Structural sensors and actuators are transducers that are attached or embedded in the fairing itself for the purpose of controlling the sound transmission. The use of structural sensors and actuators is motivated by the physical limitations of a payload fairing, such as the dynamic envelope for the payload and other hardware such as guidance, navigation and control and separation hardware. Structural sensors and actuators would be less intrusive because they could be attached to, or embedded in, the surface of the fairing itself. In a past effort, Leo and Anderson demonstrated that distributed sensors and actuators were a feasible means of modifying interior acoustic response by at least several dB. Furthermore, distributed sensors and actuators have the added benefit of mass loading the fairing to decrease the sound transmission at higher frequencies.

This work also concentrates on the use of local feedback control for active acoustic attenuation. The lack of a reference signal correlated with the disturbance makes the use of feedforward control impractical. Furthermore, the complexity of the structural-acoustic model for the payload fairing makes global structural control extremely difficult. For these reasons, only local feedback control schemes are considered in this paper.

The objective of the work was to assess the feasibility of active acoustic attenuation for launch vehicle payload fairings. This was partially accomplished through an analytical and experimental program on an existing composite payload fairing. This fairing, the STARS fairing, is shown in Figure 2 sitting on a test stand. The STARS fairing is a 54 inch maximum diameter, 172 inch long, composite payload fairing, built by McDonnell Douglas Aerospace for Sandia National Laboratories. Two flight units and an engineering test unit were built with one of the flight units being recently flown on a successful STARS launch. Sandia National Laboratories agreed to lend the engineering test unit to the Air Force for the purposes of this research. The first section of this paper describes the structural-acoustic modeling effort on the STARS fairing. The second section discusses open-loop structural-acoustic testing effort on the STARS fairing. The third section discusses the initial closed-loop experiments performed on the STARS fairing. The final section presents conclusions and plan for future work.

Figure 2. Photograph of STARS Fairing

STRUCTURAL-ACOUSTIC MODELING OF STARS FAIRING

Structural-acoustic models of the composite payload fairing can be constructed and are useful for a variety of purposes. Among these are actuator/sensor placement, control design, and performance prediction. Because the structural finite element model is based on the physical system, it can be used to model potential actuator and sensor locations and predict their ability to excite the fairing structure. When coupled to an acoustic boundary element model, the structural model can be used to predict the acoustic response to the modeled actuator locations. Another use for the structural-acoustic model is to design control laws and to predict their performance prior to actual implementation on the fairing. A structural finite element model can be joined to an acoustic finite element model to form a state space model of the combined structural-acoustic system, including actuator and disturbance inputs and sensor and performance measurements. This state space model can then be used to design control laws using modern control methods and then be used to predict performance. In this way, promising control topologies can be explored without wasting valuable testing time.

STRUCTURAL MODELING

A structural finite element model of the STARS fairing was obtained from McDonnell Douglas, the original builder of the STARS fairing. This model is a thin shell model of the composite fairing structure and includes stiffeners for the separation ring and attachment flanges. Initial normal mode runs of the finite element model in a cantilever configuration revealed that the fundamental structural mode of the fairing is a pair of bending modes at 63 Hz. The first shell mode of the fairing occurs at 75.5 Hz. To get an idea of the modal density of the fairing structure, Figure 3 shows a plot of the mode frequency versus mode number for all the structural modes up to 500 Hz. For reference, note that there are nearly 300 structural modes up to 500 Hz, while there are only 73 acoustic modes in this same frequency range. This provides an indication of the challenge of the structural control problem for the STARS fairing. At the same time, however, it also indicates the potential that the control could have in reducing the level of the acoustic field inside the fairing. Since lightly damped structural modes can lead to good acoustic transmission, a structural control algorithm that adds modest levels of damping to these modes could lead to good reduction in the acoustic transmission, which translates into attenuation of the enclosed acoustic field.

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Figure 3. Modal density of STARS structural model

In order to better simulate the boundary conditions that would be present with the fairing attached to the launch vehicle, a test stand would be required during testing. This test stand mimics the mounting present on the launch vehicle and close off the bottom of the fairing to form a cavity. During the design of the fairing test stand, some concern was expressed that the large top plate of the stand would act like a drum head and would be the dominant radiating structural mode of the combined fairing and test stand structure. There were several ways to minimize the likelihood of this occurring. The first of these was to make the drum head mode of the plate very high in frequency, in other words to increase its stiffness. It is well known that one of the most effective ways to prevent acoustic transmission is to simply add mass. Thus, the second approach was to make the plate massive enough that its inertia prevents much transmission from taking place. Both of these methods were employed in the test stand, which employs a 1.5 inch thick plywood layer and a .5 inch thick aluminum layer. The combined plate is stiff and very massive, weighing in excess of 300 lbs with the total fairing mass being on the order of 200 lbs. To find the first drum head mode of the plate, a finite element model of the test stand was constructed. This model revealed that the drum head mode, shown in Figure 1, occurred at 213.5 Hz, which is well above the first panel modes of the fairing which occur at 75.5 Hz.

In order to properly compare the structural finite element model with subsequent modal tests, a model of the test stand was added to the shell model of the fairing. This model is shown in Figure 4. Due to the unknown mounting of the fairing on the test stand, the model of the fairing was tied down to the test stand using rigid links. The result of this connection is that the flexible modes of the fairing are essentially the same as those of the cantilever fairing model presented above.

ACOUSTIC MODELING

An acoustic finite element model was constructed for the STARS fairing and the normal modes of the enclosed acoustic field were found using an acoustic finite element model. The model consisted of 32 lengthwise elements, 6 radial elements, and 28 circumferential elements for a total of 6160 elements. COMET/Acoustics was used to find the lowest 6 normal modes, which are summarized in Table I. The axial mode index indicates the number of nodal pressure planes along the length of the fairing and the circumferential mode index indicates the number of nodal diameters in the circular cross-section.

Figure 4. Structural Finite Element Model of STARS fairing and test stand

Table I. Comparison of Experimental and Analytical Acoustic Modal Frequencies for STARS Payload Fairing

Measured Frequency (Hz)	Analytical Frequency (Hz)	Percent Difference	Axial Modenumber	Circumferential Modenumber
55.82	51.54	-7.7	1	0
94.45	92.18	-2.4	2	0
135.37	133.73	-1.2	3	0
152.38	157.45	3.3	0	1
172.45	175.25	1.6	4	0
174.74	176.93	1.3	1	1

Figure 5 shows the modal frequency versus mode number for the STARS acoustic model. Note that there are 73 modes below 500 Hz, much less than the structural model. The fundamental mode of the acoustic model is at 51.5 Hz compared to a first shell mode of the fairing of 75.5 Hz. Note that all acoustic modes below 330 Hz are either axial or circumferential and the first radial mode occurs at 330 Hz. Because most of the acoustic modes below 500 Hz are axial in nature and structural actuator locations are limited to locations that will drive the shell modes of the structure, structural control will have virtually no authority over these axial modes. The first circumferential mode occurs at 157 Hz, approximately twice the frequency of the first shell modes of the fairing structure. This means that there will be limited coupling between the structural shell modes and circumferential acoustic modes and purely structural control will have difficulty affecting the acoustic levels of the fairing interior.

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Figure 5. Modal density of STARS acoustic model

STRUCTURAL-ACOUSTIC TRANSMISSION

Structural-acoustic transmission analyses were performed on the STARS fairing using the COMET/Acoustics boundary element code. In these analyses, a single monopole source was placed to one side and below the fairing to simulate the acoustic field present at launch. The acoustic field inside the fairing was solved frequency by frequency at selected points. Figure 6 shows the average sound pressure level inside the fairing versus frequency. Note that the large spike at 50 Hz is clearly the fundamental acoustic mode. The nature of the other large peaks at 140 Hz and 190 Hz are less clear. These peaks are not in the vicinity of acoustic modes, but are in the frequency range where there are numerous panel modes of the structure. It is likely, therefore, that these peaks are due to structural modes of the shell structure. It should be pointed out that no damping was included in the structural model and these peaks are probably much higher than they would be in reality. The fact, however, that there is significant acoustic transmission due to structural modes indicates the potential for significant improvement in the transmission loss characteristics of the fairing due to active structural-acoustic control.

STRUCTURAL-ACOUSTIC TESTING OF STARS FAIRING

Because much of the control design work for the STARS fairing, such as sensor and actuator placement, control law design, and performance prediction, rely on the analytical models derived above, it is imperative that these models be validated against experimental data. The primary purpose of the structural-acoustic tests, therefore, is to gather the experimental data that will be used to validate the analytical models. A secondary purpose of the testing is to establish a baseline for the subsequent noise reduction testing. The testing that was conducted falls into the following categories:

- structural modal tests – obtain frequency, modeshape, and structural damping information for validation of the structural model
- acoustic modal tests – obtain frequency, modeshape for validation of the acoustic model
- reverberant field tests – measure structural response and internal acoustic response to external reverberant field, establishes the baseline for subsequent control tests
- structural-acoustic transfer function tests – obtain transfer functions from structural excitation to internal acoustic pressure, providing information about the force levels required to generate a certain internal SPL and information to validate actuator placement

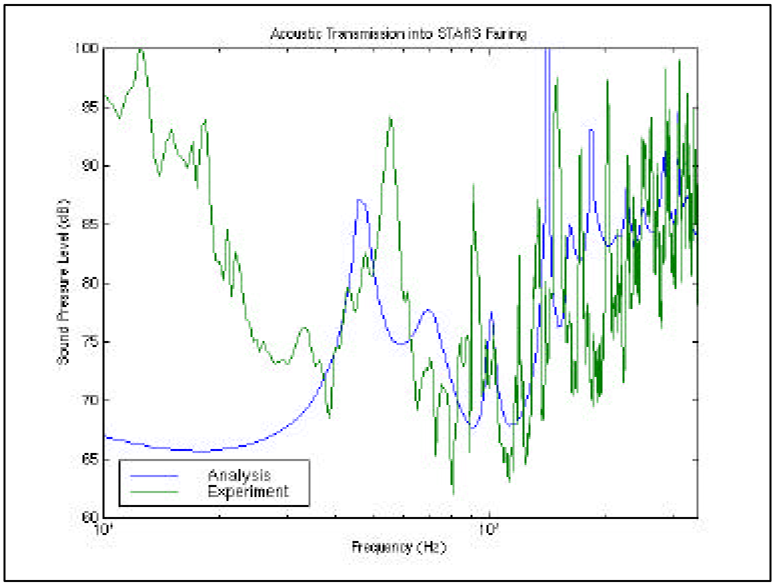

Figure 6. Analytical and Experimental transmitted sound pressure levels inside the STARS fairing from an exterior source

STRUCTURAL MODAL TESTING

The combined finite element model of the fairing and test stand indicates that there are approximately 170 modes below 350 Hz, with 155 of them being shell modes of the fairing. To capture these modes, an array of accelerometer locations consisting of 24 locations around the circumference of the fairing and 10 rows along the length of the fairing was chosen. At each location, an accelerometer triax was placed and used to measure motions in three directions. Since that many accelerometer triaxes were not available, the accelerometers were used in a roving fashion in several tests until all locations had been measured. Mass simulators were placed at the unused locations so that the mass distribution on the fairing was consistent from test to test. In addition to the fairing locations, five or six locations on the test stand were also be measured so that the effect of the test stand on the fairing behavior could be better understood. Figure 7 shows a photograph of the STARS fairing undergoing modal testing. Note the shakers attached near the nose of the fairing, the accelerometer triaxes and cabling, and accelerometer mass simulators.

The modal test results indicate a fundamental bending mode at 13.8 Hz with 10 modes up to 56.0 Hz, while the model predicts a fundamental at 38.2 Hz. The reason for this extremely large discrepancy is unclear. Possible explanations include improper modeled boundary conditions and not including the mass simulators at the measurement locations. The most likely explanation is that the actual test boundary conditions at the bottom of the fairing were much softer than were modeled. The key point, though, is that this mismodeled bottom boundary condition predominantly affects the bending behavior of the fairing. From an acoustic transmission perspective, these bending modes are not very well coupled to the acoustic field and do not radiate very well. Thus, although, the large error in the fundamental bending mode is a little troubling, the fact that the panel modes of the fairing are not appreciably affected by the error means that the model should still be reasonably accurate for use in the rest of the active acoustic control effort.

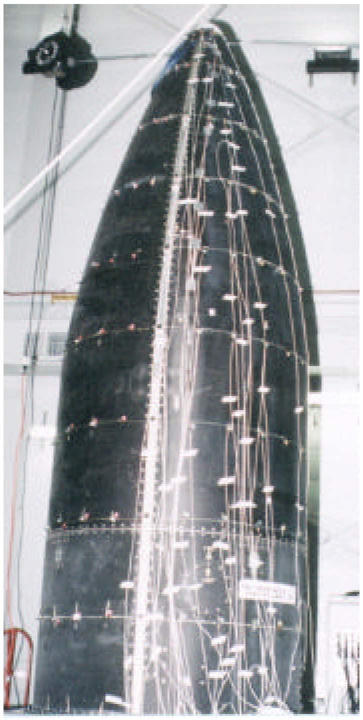

Figure 7. Structural modal testing of STARS fairing

ACOUSTIC MODAL TESTING

An acoustic modal test of the fairing interior cavity was performed. This modal test consisted of inserting a speaker inside the fairing and measuring the acoustic pressure at many locations inside the fairing. The interior acoustic field was measured using a microphone array shaped like a tree. Figure 8 shows a photo of the microphone tree inside the fairing. The microphone tree consists of twelve planes of microphones along the axis of the tree. Each plane consists of three radials of microphones with a 120 degree angular spacing between each line. Each radial of microphones is mounted on a thin tubular rod. The three radials of microphones are attached to the central pole with collars that are held in place with set screws. This arrangement allows the heights of the planes to be adjusted. An additional feature of the microphone tree center pole is that it can be rotated, allowing more angles to be measured than just the three rods separated by 120 degrees. The microphones are low-cost electret microphones mounted in a polycarbonate housing. This arrangement of the microphone housing allows adjustment of the radial distance from the central axis for each microphone. In addition to allowing the location of the microphones to be varied, the collar and microphone housing arrangement allows easy reconfiguration of the array for other fairing geometries and the inclusion a payload simulator.

A comparison of these measured frequencies and the analytical frequencies is shown in Table I, along with a description of the mode. Note that the first radial mode does not occur until approximately 330 Hz. The fundamental frequency of the analytical model is in error by 7.7 percent. A likely explanation for this error is that the acoustic finite element model was constructed based on the outer mold line (OML) of the STARS fairing rather that the inner mold line (IML).

An addition concern with the fairing acoustics is that the acoustic modal frequencies of the fairing cavity will change with the presence of a payload. This is the well known payload fill effect. Because the acoustic modal frequencies of the fairing cavity change with different payload size and geometry, any control design for the fairing must be robust to these changes. This means that the control laws must not rely on inverting the acoustic modal frequencies. Rather, the control law must use purely structural sensors or acoustic sensors collocated with the actuators for feedback.

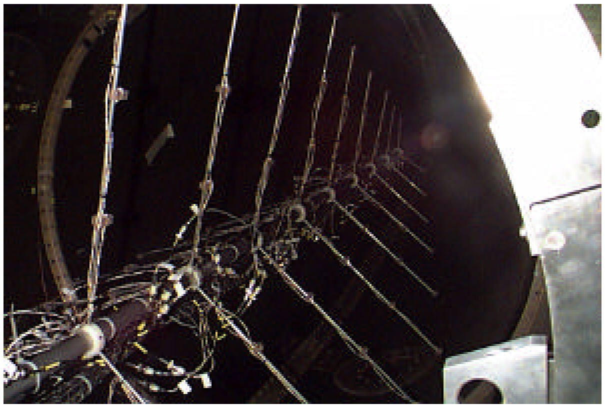

Figure 8. Microphone tree inside STARS fairing during acoustic modal testing

TRANSMISSION TESTING

Open-loop acoustic transmission testing was performed on the STARS fairing. This configuration for the transmission testing was as follows. A single large subwoofer speaker was set up on the ground outside the fairing. White noise was played through the speaker that impinged on the fairing. The internal acoustic response was then measured using the microphone tree from the acoustic modal test. Ideally, this type of testing is performed in a reverberation room so that the incident acoustic intensity on the fairing is equal on all sides. Because of the size of the room in which the fairing is installed and the small size of the speaker, the conditions of the test cannot be considered reverberant. Instead, the test conditions were more reminiscent of the actual launch conditions where there are one or more point sources located to the side and below the fairing. This situation was modeled above using a coupled boundary element / finite element analysis. Figure 6 compares the analytical and experimental acoustic transmission results using an average along the centerline of the fairing. Note that the analytical results have been scaled to roughly match the experimental results in magnitude. This type of transmission analysis is the most complicated type of analysis that can be performed using boundary element techniques. Considering the difficulty of the analysis, the relatively good agreement of the analysis with the data provides rather convincing proof of the validity of both the structural and acoustic models.

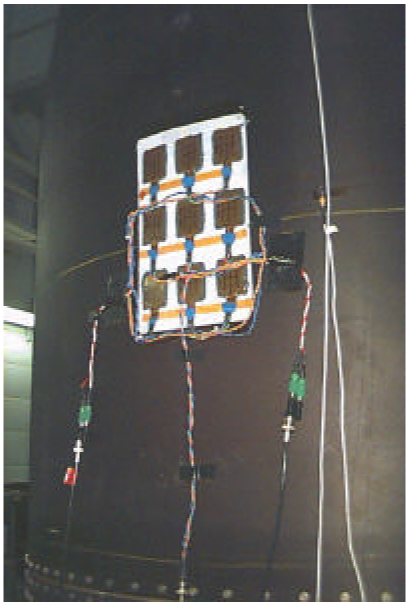

Figure 9. Photograph of piezoelectric actuators on STARS fairing

CLOSED-LOOP TESTING

Because of concerns about cost and the need to maintain flightworthiness of the STARS fairing, a full-scale implementation of the active control system was not pursued on the STARS fairing. Instead, the STARS fairing was used to gain experience with the implementation of structural-acoustic control using collocated structural actuators and structural and acoustic sensors. For the scaled back STARS control testing, a total of nine piezoelectric patch actuators were bonded to the fairing in a 3 × 3 array, as shown in Figure 9. The piezoelectric actuators cover 24 in^2 of the fairing out of a total surface area of 22525 in^2, or 0.1% of the total fairing surface area. The outer eight patches are used as actuators, while the center patch is used as a strain sensor. In addition to these structural sensors, an acoustic sensor was also attached to the fairing. Figure 10 summarizes the test configuration. Figure 11 shows the transfer function between the eight actuated patches and the single sensing patch. Note the alternating pole-zero pattern characteristic of collocated transfer functions.

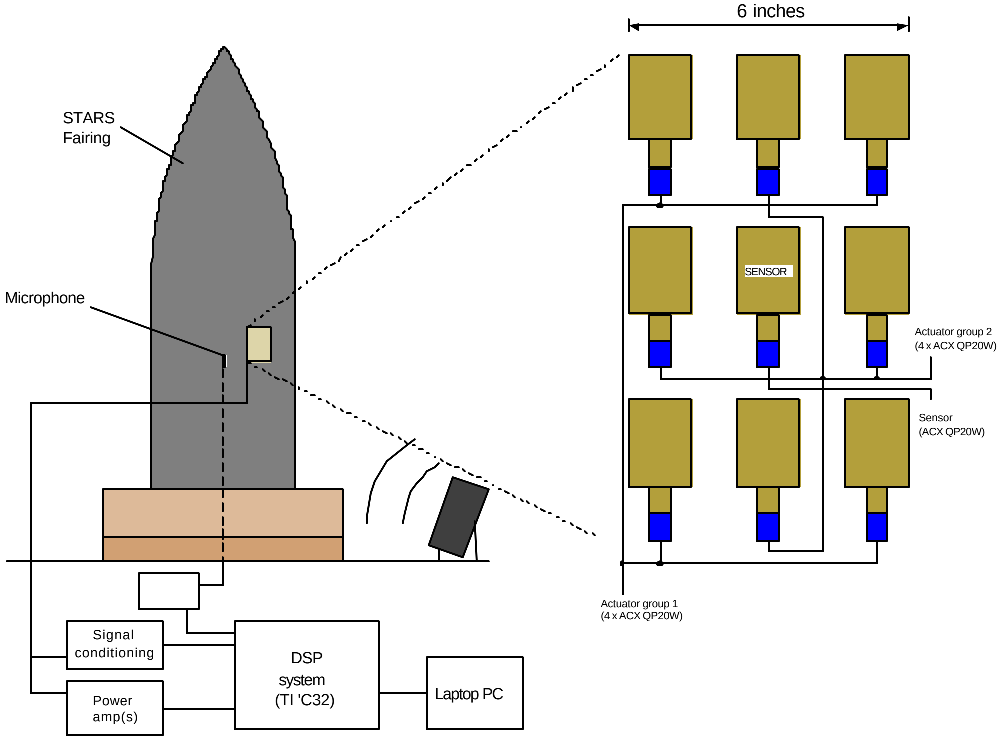

Figure 10. Schematic of control implementation for STARS fairing

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Figure 11. Collocated transfer function from piezo actuators to piezo sensor

One of the primary concerns in conducting control tests on the STARS fairing is that the fairing be returned in flightworthy condition. This means that all actuators and sensors were removed at the conclusion of testing. The microphones do not have to be bonded directly to the fairing, but can be bonded to a piece of kapton tape instead. The problem of removal poses a problem for the actuators because any material placed between the piezoceramic wafer and the structure reduces the effectiveness of the actuator by acting as an added compliance. Because of this concern, a buffer material of kapton tape was inserted between the actuators and the fairing. Later tests revealed that the piezoelectric actuators were not damaged during subsequent removal.

Three types of control laws were be implemented on the STARS fairing:

1. local structural control—feedback of the collocated strain sensors to the actuator array
2. global structural-acoustic control—feedback of a microphone on the tree to the actuator array
3. local structural-acoustic control—feedback of local microphone to the actuator array

At least one compensator from each control law type was implemented on the fairing for a total of six compensators. Each controller was implemented as a single input, single output controller, with a 12000 Hz sampling rate. The compensators ranged from a low order of two states to a much higher order of 50 states. Each controller was implemented using a Texas Instruments TMS320C32 DSP running at 60 MHz.

Figure 12 shows the open and closed-loop responses from an external speaker to the piezo strain sensor mounted on the fairing for the first type of control law. In this topology, two low order controllers were implemented on the fairing with the control objective being active damping enhancement of the fairing structure. The plot shows that the damping of structural modes below 150 Hz was significantly increased by the active control. Figure 13 shows the open and closed-loop responses from the external speaker to four internal microphones for the same two controllers as shown in Figure 12. Note that the high closed-loop damping ratios do not translate into strong reductions in the acoustic field inside the fairing. The largest attenuation of the acoustic field occurs at the structural modes at 100 Hz and 180 Hz. This is not unexpected because the input disturbance is broadband in nature and a reduction in the vibration levels of a structural mode (increased damping) will naturally translate into reduction in the acoustic field. Note that there is essentially no attenuation of the large acoustic mode at 55 Hz, which again is not unexpected, since it was previously pointed out that there is limited coupling between the fairing structure and the axial modes of the enclosed acoustic field.

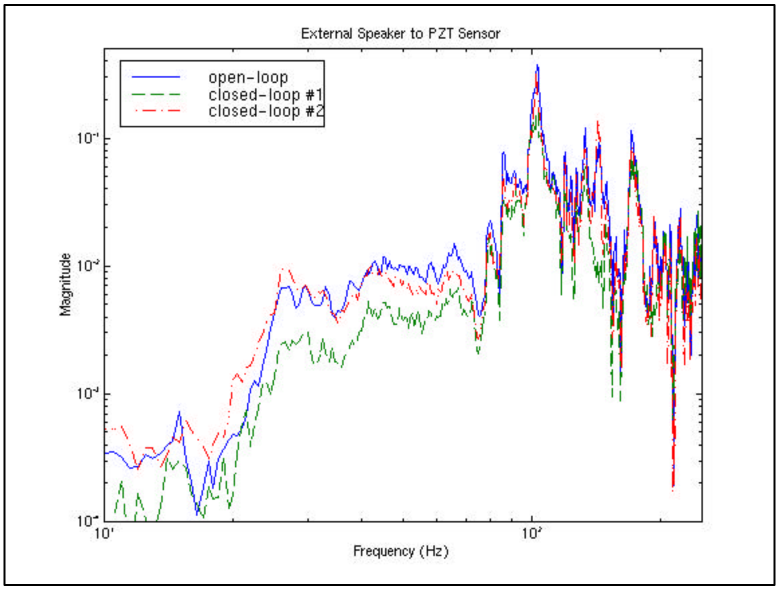

Figure 12. Closed-loop response from external speaker to piezo strain sensor

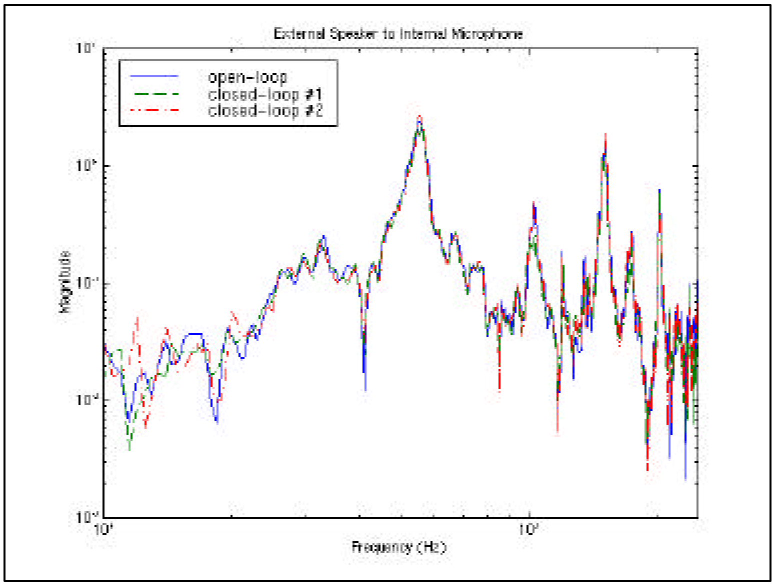

Figure 13. Closed-loop response from external speaker to internal microphone

Controllers were designed based on the other two control topologies, but instabilities resulted during implementation. The instabilities were later attributed to a mix-up in labeling of the microphone channels that were used for feedback, the result of which was that different microphones than were intended were actually fed back. Time constraints, imposed by the need to return the STARS fairing to Sandia National Laboratories on time, prohibited correcting the labeling problem and implementing the control laws correctly.

CONCLUSIONS

Modeling and experimental results have been presented for a full size fairing, the STARS fairing built by McDonnell Douglas for Sandia National Laboratories. Structural-acoustic models of the STARS fairing were constructed and used to perform preliminary actuator placement, acoustic transmission, and acoustic control studies on the fairing. Structural and acoustic modal tests were performed on the fairing to gather data that was used to validate the structural and acoustic models of the STARS fairing. Open-loop transmission tests were also performed on the fairing from an external speaker to an internal microphone array, establishing a baseline for subsequent closed-loop tests. Control laws of three different topologies were designed and implemented on the fairing. Only two controllers of a single topology were implemented successfully due to a mix-up in labeling of feedback channels. The closed-loop results indicated that good structural damping enhancement could be achieved using a piezo strain sensor fed back to an array of eight piezo actuators. This structural damping, however, did not translate into equal attenuation of the enclosed acoustic field. Subsequent research in this area will focus on active acoustic control applied to a grid-stiffened fairing being built by Boeing for the Minotaur program. In this effort, a full implementation of the techniques developed for the STARS fairing will be applied to the Minotaur grid-stiffened fairing.

ACKNOWLEDGEMENTS

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