

# **Structural & Internal Acoustic Response of Cylinders with Applications to Rocket Payload Fairings**

Christopher Niezrecki

Dissertation submitted to the Faculty of Virginia Polytechnic Institute and State University in  
partial fulfillment of the requirements for the degree of

Doctor of Philosophy  
in  
Mechanical Engineering

Harley H. Cudney, Chair  
Ricardo Burdisso  
Ramesh Batra  
Alok Das  
William Saunders  
Alfred L. Wicks

May 1999  
Blacksburg, Virginia

Keywords: Simply-Supported, Cylinder, Fairing, Acoustic, Actuator  
Copyright 1999, Christopher Niezrecki

# **Structural & Internal Acoustic Response of Cylinders with Applications to Rocket Payload Fairings**

Christopher Niezrecki

(ABSTRACT)

Future launch vehicle payload fairings will be manufactured from advanced lightweight composite materials. The loss of distributed mass causes a significant increase in the internal acoustic environment, causing a severe threat to the payload. Using piezoelectric actuators to control the fairing vibration and the internal acoustic environment has been proposed. The control authority of these actuators for this problem has not yet been determined. To help determine the acoustic control authority of piezoelectric actuators mounted on a rocket fairing, the internal acoustic response created by the actuators needs to be determined. In this work the internal acoustic response of a closed simply-supported (SS) cylinder actuated by piezoelectric (PZT) actuators is presented. A research-grade SS cylinder is created and the modal properties are analyzed experimentally. The experimental modal properties are compared to finite element analysis (FEA) and to results predicted by Love shell theory. The experimental results indicate that the created cylinder has dynamic properties that are similar to the analytical and FEA results. The formulation for the structural response uses an impedance model to predict transverse vibration of the cylinder excited by PZT actuators. The model is also shown to be valid. To obtain the internal acoustic response of the cylinder a boundary element analysis using the Kirchoff-Helmholtz integral is used. The motion of the structure is assumed to be uncoupled with the internal acoustics, and so the structural-acoustic interaction is not considered in this analysis. An analytical solution to the internal acoustic response within the cylinder is derived for a single mode structural vibration. The numerical and analytical models are shown to be in agreement. The numerical model is also verified experimentally by measuring the acoustic field within the cylinder. The experimental results and the results predicted by the acoustic model are in agreement. A measure of the acoustic loss factor for the aluminum cylinder is also determined experimentally.

The validated model is used to extrapolate results for a SS cylinder that emulates a Minotaur payload fairing. The internal cylinder acoustic levels are investigated for PZT actuation between 35 and 400 Hz. It is found that changes in cylinder parameters (stiffness and material density) do not have a large effect on the magnitude of the structural response. Likewise the interior acoustic response is not greatly affected by changes to the cylinder parameters. As the applied voltage increases linearly, the internal sound pressure level (SPL) varies logarithmically. This

behavior is a limiting factor in using a PZT actuator to generate high internal SPLs. Significant reductions in the structural response due to increased damping do not equate to similar reductions in the acoustic SPLs for the cylinder. The sound levels at the acoustic resonant frequencies are essentially unaffected by the significant increase in structural damping while the acoustic levels at the structural resonant frequencies are mildly reduced. The interior acoustic response of the cylinder is dominated by the acoustic modes and therefore significant reductions in the overall interior acoustic levels will not be achieved if only the structural resonances are controlled.

The model indicates that the maximum acoustic levels generated by the baseline PZT actuator are sufficient at the higher frequency range but are not commensurate with the levels found in a typical fairing in the lower frequency range (below ~200 Hz). Since the baseline actuator's applied voltage can not be increased, additional actuators are required in order to increase the response of the cylinder at some of the lower frequencies. The baseline actuator is clearly better at generating sound within the cylinder as the frequency increases. This implies that more actuators will be required to control the lower frequency modes than the higher frequency modes. As the actuation frequency is reduced, the number of actuators required to generate acoustic levels commensurate to that found in the fairing increases to impractical values. Below approximately 100 Hz, the current demands reach levels that are extremely difficult to achieve with a practical system. The results of this work imply that PZT actuators do not have the authority to control the payload fairing internal acoustics below ~100 Hz.

## **ACKNOWLEDGEMENTS**

I would like to express my gratitude to some of the people who contributed to this work. I would like to first thank Dr. Harley H. Cudney for his instructions, directions, and professional advice. He truly exemplifies the role of advisor. I would also like to thank Dr. Ricardo Burdisso who gave me sound technical advice to more than a handful of acoustic and vibrations questions. I would also like to thank Dr. Frederic Lalande for creating an impedance model of a piezoelectric actuator and helping me to understand it.

The Air Force Office of Scientific Research and Phillips Laboratory (Kirtland AFB, Albuquerque, NM) also deserves my thanks in funding my research and allowing me to work there.

I would also like to express my appreciation to my friend and colleague Dr. Hartono Sumali for many helpful and insightful discussions. Thanks are also extended to Gyuhae Park for making the work in the laboratory much less tedious.

Lastly, I would like to thank Amy E. Brodeur for helping me to keep my focus and sanity through this long and arduous process.