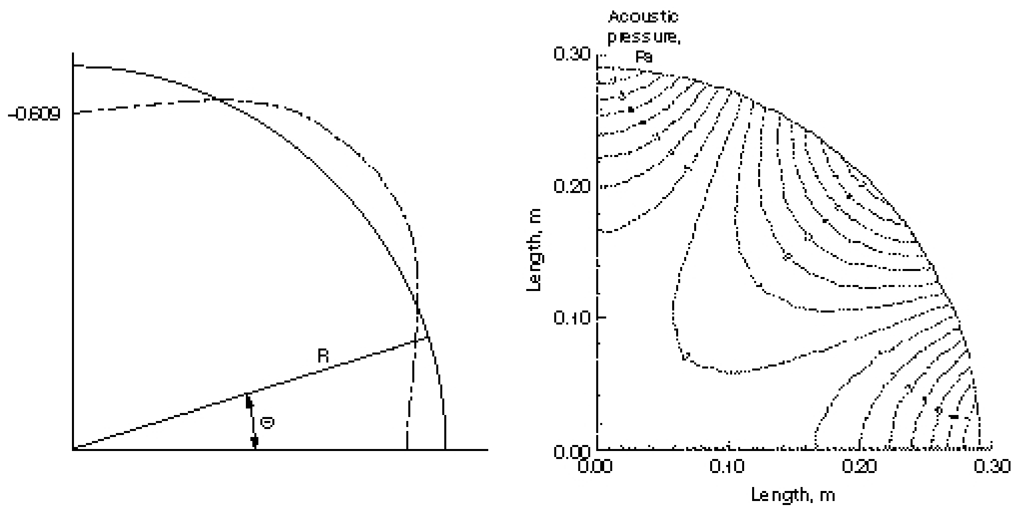
Novel Multidisciplinary Models Assess the Capabilities of Smart Structures to Manage Vibration, Sound, and Thermal Distortion in Aeropropulsion Components

The development of aeropropulsion components that incorporate "smart" composite laminates with embedded piezoelectric actuators and sensors is expected to ameliorate critical problems in advanced aircraft engines related to vibration, noise emission, and thermal stability. To facilitate the analytical needs of this effort, the NASA Lewis Research Center has developed mechanics and multidisciplinary computational models to analyze the complicated electromechanical behavior of realistic smart-structure configurations operating in combined mechanical, thermal, and acoustic environments. The models have been developed to accommodate the particular geometries, environments, and technical challenges encountered in advanced aircraft engines, yet their unique analytical features are expected to facilitate application of this new technology in a variety of commercial applications.

This multidisciplinary effort encompasses analytical and computational developments in three disciplines. The first area involves a generalized curvilinear laminate theory and specialty finite elements for laminated composite shell structures with curved piezoelectric actuators and sensors (ref. 1). These novel curvilinear piezoelectric finite elements use different, yet adjustable, representations for the displacements and electric potential which can be adapted to capture the configuration of the laminate and the embedded piezoelectric devices. They enable efficient and accurate modeling of three-dimensional, smart composite shell structures of any shape, curvature, or laminate configuration.

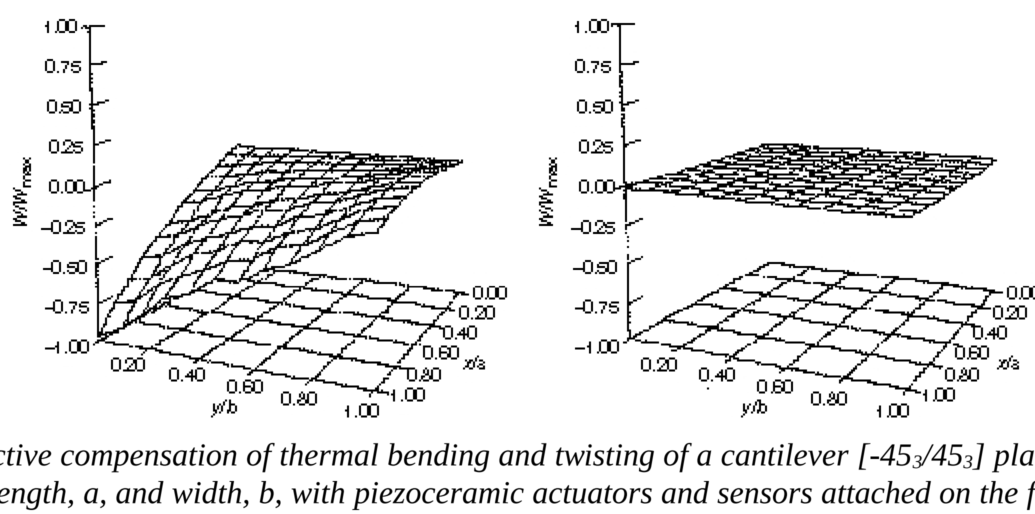
The second area involves computational models for analyzing the coupled vibroacoustic response of smart shell structures that enclose acoustic fluids (ref. 2). These interdisciplinary models, which effectively provide coupled solutions by using the previously mentioned structural finite element models with acoustic boundary element methods, are a necessary step toward the development of smart structures that can control noise.

In the third area, admissible computational models have been developed to quantify the performance of piezoelectric structures in thermal environments (ref. 3). Besides helping us to understand and quantify the effect of thermal loads on the performance and structural integrity of smart structures, this work has enabled us to formally study the feasibility of active thermal distortion management.



Coupled steady-state response of a smart cylindrical containment structure (quarter model) with piezoceramic actuators attached on the outer surface excited at 200 Hz. Left: Induced dynamic deflections. Right: Induced acoustic pressure (in pascals) in the enclosed air.

The successful development and coupling of these models has resulted in a multidisciplinary computational platform that can simulate the coupled mechanical, electrical, thermal, and acoustic response of a smart structure. Such simultaneous predictions of the dynamic deflections of the smart structure and the interior acoustic pressure field, both induced by piezoelectric actuators embedded in the smart structure, are shown in the previous figure. The following figure shows the effects of a thermal gradient applied on a cantilever plate with attached piezoceramic patches. These effects typically include thermal distortions (left side of figure) and changes in sensory electric signals, as well as the ability to enhance thermal stability and to use piezoceramic actuators to compensate for thermal distortions (right side of figure).



Active compensation of thermal bending and twisting of a cantilever [-45$_3$/45$_3$] plate of length, a, and width, b, with piezoceramic actuators and sensors attached on the free surfaces. Left: Thermal distortion, w, induced by thermal gradient. Right: Compensation *of thermal distortion by simultaneous application of electric potential on actuators.*

References

1. Saravanos, D.A.: Coupled Mixed-Field Laminate Theory and Finite Element for Smart Piezoelectric Composite Shell Structures. NASA CR-198490, 1996.

2. Kaljevic, I.; and Saravanos, D.A.: Coupled Analysis of Smart Structures Surrounding Acoustic Enclosures. AIAA Paper 96-3996, 6th AIAA/USAF/NASA/ISSMO Symposium on Multidisciplinary Analysis and Optimization, Bellevue, WA, Sept. 4-6, 1996.

3. Saravanos, D.A.; and Lee, H.J.: Layerwise Finite Elements for Smart Piezoceramic Composite Plates in Thermal Environments. AIAA Paper 96-1277 (NASA TM-106990), 1996.

Lewis contact: Dimitris A. Saravanos, (216) 962-3211, dsaravanos@grc.nasa.gov
Author: Dimitris A. Saravanos

Headquarters program office: OA