Coupled Electromechanical-Vibroacoustic Modelling Of A Piezoelectric Synthetic Jet Actuator

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Abstract

Synthetic jet actuators enhance flow control by generating pulsatile jets with zero net mass flux. There is a need to develop a computationally inexpensive model that can generate optimal geometric actuator designs of maximum jet performance. This work investigates the multi-physics behavior of a piezoelectrically driven actuator, focusing on the coupling between electrostatics, structural dynamics and internal acoustic domain using COMSOL.
First, a finite element model of the circular piezoelectric bimorph configuration is built and validated via modal testing using scanning LDV measurements to obtain structural natural frequencies and damping ratios. Next, acoustic resonance frequencies of the actuator's cavity are determined using the pressure acoustic solver, in addition with narrow region acoustics to capture damping as a simplification of full thermos-viscous acoustics. The diaphragm FEM is then coupled with the acoustic domain to evaluate coupled resonant frequencies and mass-loading effects, demonstrating that the displaced internal air lowers the natural frequency of the diaphragm compared to the uncoupled structural case. This coupled FEM-acoustic model also provides pressure and velocity fields at the orifice for any driving frequency, allowing for rapid evaluation of jet performance without requiring transient fluid simulations. With this model, frequency-domain optimization is performed to maximize jet performance through a metric termed "instantaneous acoustic thrust," allowing large-scale parametric sweeps over varying cavity heights and orifice widths.
A high-fidelity CFD run is reserved for a standalone evaluation of the single optimal design to capture detailed flow structures and jet velocity profiles, thus avoiding repeated optimization loops. It is expected this approach will deliver improvements in instantaneous acoustic thrust near the coupled resonance frequency however it remains to be validated with a detailed computation of the flow field. The final step will include an assessment of the fidelity of the surrogate "instantaneous acoustic thrust" metric against detailed CFD outcomes.

Reference

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Figures used in the abstract

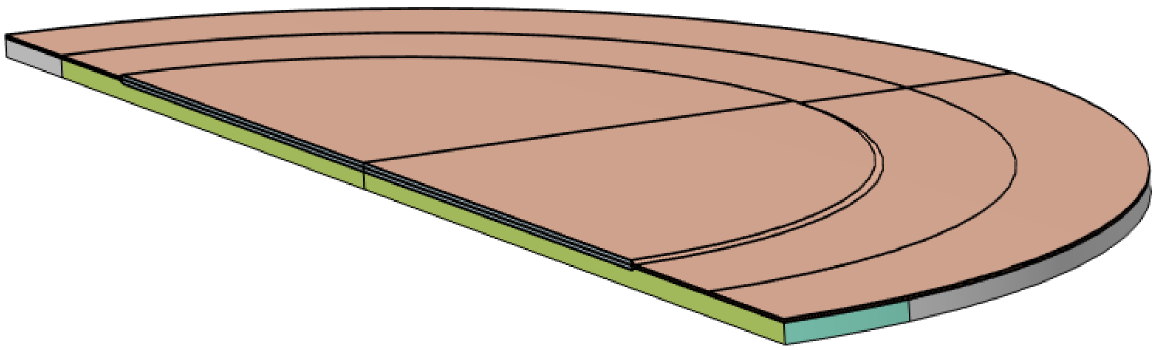

Figure 1 : Symmetrical quarter model of the SJA baseline geometry

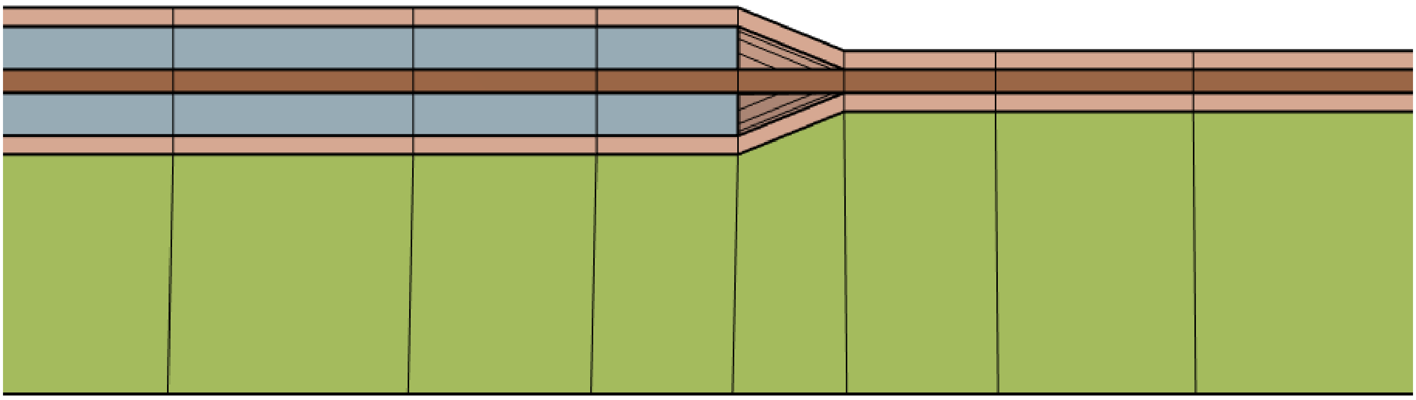

Figure 2 : Internal view of the piezo bimorph membrane configuration in contact with the internal cavity air domain (green)

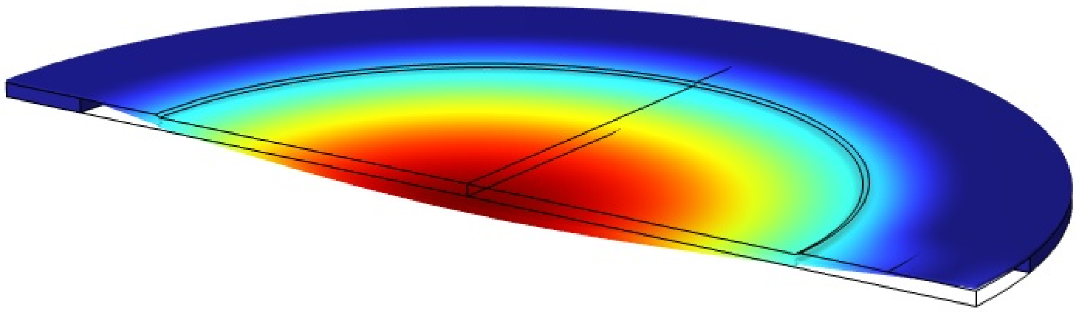

Figure 3 : Baseline SJA displacement plot driven at 100Vrms and 207Hz (optimal frequency assuming constrained max membrane displacement to prevent interference)

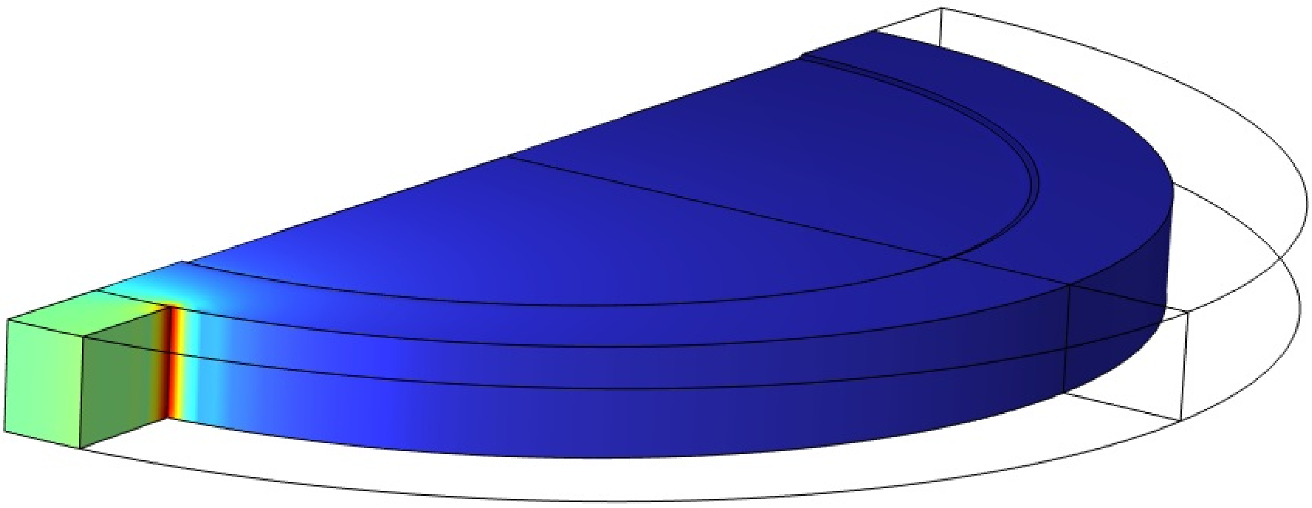

Figure 4 : Optimal SJA configuration considering cavity height, orifice width and driving frequency