

Reducing Cavity Response in Strongly Coupled Acoustic-Structure Systems

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Extended Abstract

1 INTRODUCTION

When a vibrating structure is adjacent to a fluid-filled cavity, the potential for acoustic-structure coupling exists. The coupling effects are most pronounced when a pair of uncoupled structural and acoustic modes are spatially similar and in close frequency proximity. In this case, the structural response resembles that of a tuned-mass-damper (TMD), where a single structural resonance is replaced with two acoustic-structure resonances. The coupling somewhat attenuates the amplitude of the structural resonances relative to the corresponding uncoupled resonance. However, strong acoustic-structure coupling drives energy into the cavity and results in acoustic resonances that are much larger than they are in more weakly coupled configurations [1]. Amplification of acoustic response is rarely desirable in mechanical, aerospace, and civil engineering applications, and here we seek an effective means of reducing cavity response in strongly coupled situations. Specifically, this work considers the possibility of reducing cavity response by integrating a tuned attachment mass to the primary structure. To assess the effectiveness of this approach, we theoretically and experimentally consider a piston coupled to a one-dimensional (1D) waveguide [1, 2]. This prototypical system enables the effectiveness of the noise reduction approach to be assessed across a wide parameter space.

2 MODEL

A schematic for the system of interest is shown in Fig. 1. The two degree-of-freedom structural subsystem is composed of a piston with an attachment mass. The piston is coupled to a one-dimensional acoustic waveguide. Equations for the uncoupled natural frequencies as well as the nondimensional frequency tuning and mass ratios are listed in Table 1. The modeling procedure for the piston/waveguide system is detailed in Davis and Schultz [1].

Uncoupled Frequencies	Tuning Ratios	Mass Ratios
$\omega_1 = \sqrt{\frac{k_1}{m_1}}$	$\beta_1 = \frac{\omega_1}{\omega_a}$	$\mu_1 = \frac{m_1}{\rho_0 AL}$
$\omega_2 = \sqrt{\frac{k_2}{m_2}}$	$\beta_2 = \frac{\omega_2}{\omega_1}$	$\mu_2 = \frac{m_2}{m_1}$
$\omega_a = \frac{\pi c_0}{L}$		

TABLE 1: System parameters

For this study, the structural damping, ζ_s and acoustic damping, ζ_a are set to 1% and 0.1%, respectively. The ratio of the attachment mass to the piston mass, μ_2 , is also fixed at 0.1. The acoustic response of the waveguide is solved numerically with and without

changes in β_1 than changes to μ_1 . As β_1 increases, the optimal frequency tuning, β_2^{opt} , decreases in a roughly linear manner.

Fig 3b (b) plots the CRF for the optimized configuration across the span of β_1 and μ_1 values. Lower CRF values are observed with increasing mass ratio. When considering the relationship between CRF and β_1 , the trend shows minimum CRF values tend to occur (at least for large mass ratios) when $\beta_1 \approx 1$. The minimum computed value of CRF is approximately -28 dB. This occurs when $\mu_1 = 1000$, $\beta_1 = 0.99$, and $\beta_2^{opt} = 1.02$.

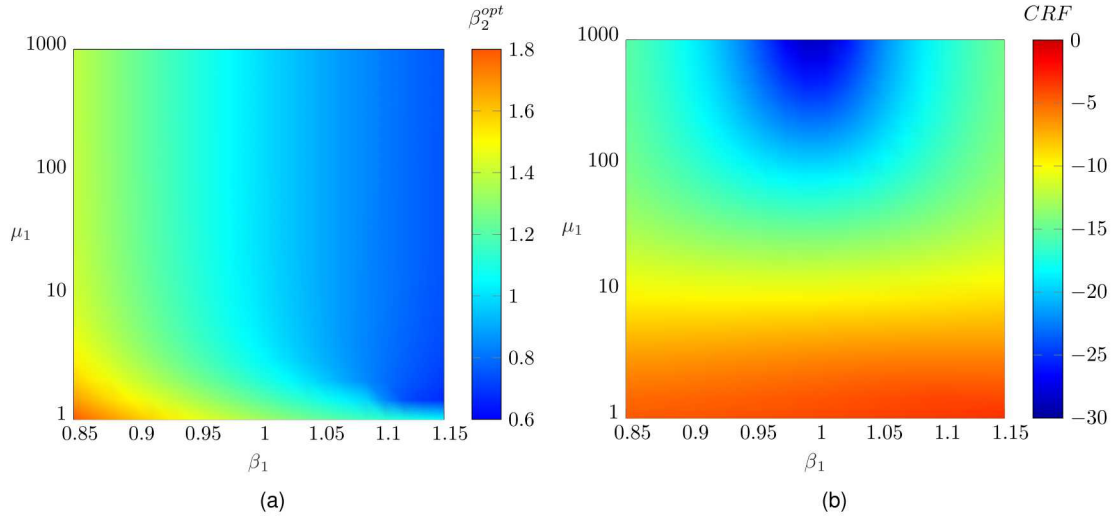


Figure 3: (a) Optimized frequency tuning, β_2^{opt} , and (b) cavity reduction factor, CRF, versus the span of frequency tuning and mass ratio, β_1 and μ_1 . Values for β_2^{opt} are determined from a gradient-based optimization that minimizes CRF. CRF is computed by comparing the integrated mean square cavity pressures for a given configuration with and without m_2 .

4 EXPERIMENT

The results of the numerical study will be validated with experiments. The experiments use a 3D printed piston coupled to an air-filled cylindrical tube. The piston weight and cavity length are selected such that $\mu_1 \approx 10$ and $\beta_1 \approx 1$. The piston is elastically restrained with a coil spring. Similar to the numerical study, there are two experimental cases: one in which the piston has an integrated attachment mass, as seen in Fig. 4, and one where it does not. The attachment mass resembles a clamped-clamped beam with a concentrated central mass. The attachment mass is carefully designed so that it can be tuned with $\beta_2 \approx 1$. An electro-mechanical shaker will be used to excite the piston, and the structural and cavity responses will be measured. The cavity responses with and without the attachment mass will be used to calculate CRF and the results will be compared with the numerical model.

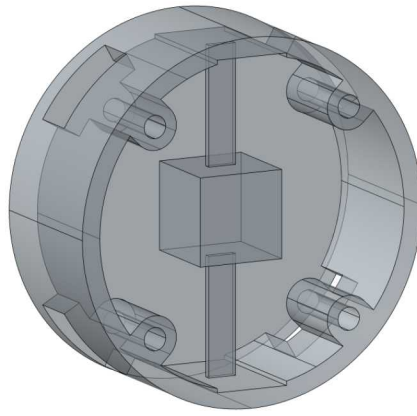


Figure 4: Piston with integrated attachment mass.

5 CONCLUSIONS AND FUTURE WORK

The numerical study demonstrates that adding a tuned attachment mass to a structure exhibiting strong coupling with an adjacent cavity can significantly reduce the acoustic response of the cavity. Over the span of μ_1 , β_1 values tested, the minimum CRF was found to be -28 dB. While this is a significant reduction in cavity response, the required μ_1 and β_1 for such a CRF may not always be feasible for a configuration of interest. The numerical study results provide insight as to the CRF that may be attainable for a given design. Ongoing experimentation will attempt to validate these results across a wide parameter space.

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REFERENCES

- [1] **Davis, R. B.** and **Schultz, R.**, "Using a Dynamic Substructuring Approach to Model the Effects of Acoustic Damping in Coupled Acoustic-Structure Systems", *J. Vibr. Acoust.*, Vol. 141, 2019.
- [2] **Ginsberg, J. H.**, "Derivation of a Ritz Series Modeling Technique for Acoustic Cavity-Structural Systems Based on a Constrained Hamilton's Principle", *J. Acoust. Soc. of Am.*, Vol. 127, No. 5, pp. 2749–2758, 2010.