MMAE SEMINAR

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Mode Switching and Linear Stability Analysis of Resonant Acoustic Flows

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Abstract

Resonant acoustic flows occur in a wide variety of practical, aerospace-related applications and are a rich source of complex flow-physics. The primary concern associated with these types of flows is the high-amplitude fluctuating pressures associated with the resonant tones that could lead to sonic fatigue failure of sensitive components in the vicinity of such flows. However, before attempting to devise methods to suppress the resonant tones, it is imperative to understand the physics governing these flows in the hope that such an understanding will lead to more robust and effective suppression techniques. To this end, an in-depth study of resonant acoustic flows, relevant to axisymmetric jets and two-dimensional cavities, has been undertaken in this thesis, the main aim being to bring about a better understanding of such flows by revealing hitherto unknown, albeit, physically relevant, information. The primary analysis tool used in this study is the compressible, inviscid linear stability theory of axisymmetric and two-dimensional shear layers. We begin by looking at the occurrence of, previously undocumented and theoretically unexpected, helical instabilities in subsonic impinging jets. For this study, we used our insight into the instability modes existing in free jets, and showed that the presence of the helical modes in our experiments could be justified. This was done by examining the dispersion relation of these instability modes in the context of linear stability analysis using a vortex-sheet model and, a more realistic, mixing-length model. The results from the work on impinging jets indicate that a study of coupled subsonic twin-impinging plume interaction, thus far considered unnecessary, is definitely warranted. Additionally, our analysis shows that since such a study holds added relevance when performed in the context of heated jets, it is directly applicable to modern fighter aircraft that have twin, closely spaced exhaust jets. Next, we look at a novel technique that yields dramatic suppression of resonant acoustic tones in subsonic flows over open cavities using high-frequency excitation. This study is a culmination of our original aim of understanding the physics governing the resonant tone generation mechanism and using this knowledge to devise a successful resonance-control strategy. Past theories that try to explain the excellent resonance suppression performance have attributed it to an enhanced stability of the shear layer of the excited flow compared to the unexcited, baseline flow. The linear stability calculations of the baseline and excited flows conducted in this thesis show that contrary to the existing theory, it is high frequency excitation and not shear layer stabilization that is responsible for the dramatic acoustic benefits. Our experimental results are in excellent qualitative agreement with our linear stability calculations for the measured mean velocity profiles. It is hoped that the work presented in this thesis will further our understanding of resonant acoustic flows in general and provide insights that can lead to better control techniques in the future.