Large Eddy Simulation of Self-Excited Diametral Acoustic Mode in Rectangular Cavities

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ABSTRACT

Self-excited acoustic resonance is a significant concern in many engineering applications such as pipelines, valves, and landing gear cavities. The free shear layer that forms across the cavity mouth, due to separated flow at the leading edge of the cavity, is intrinsically unstable within a certain frequency range. When the frequency matches an acoustic resonant mode, a fluid-resonant feedback mechanism is initiated, resulting in the amplification of the unstable shear layer and the formation of large and discrete vortex cores. These vortical structures interact with the resonant acoustic field, and if the net energy transferred to the acoustic field is greater than the energy initially extracted by the flow field to form the vortical structures, acoustic resonance can be self-sustained, resulting in high tonal noise levels.

Acoustic modes perpendicular to the flow direction (transverse) can be excited at moderate fluid flow speeds in ducted cavities, and when confinement is introduced, the resulting "trapped" modes experience negligible acoustic radiation losses. The trapped diametral acoustic modes in rectangular cavities connected to cylindrical ducts are of significant practical relevance in industrial applications as they can be readily excited at modest fluid flow rates. The flow-acoustic coupling mechanism between the unstable shear layer initiated along the cavity mouth and the transverses acoustic mode of the cavity volume can lead to the trapping of the diametral acoustic resonance in the spanwise direction, generating a complex pattern of three-dimensional flow vorticities between the leading and trailing edges. This produces strong acoustic pressures that propagate cyclically in the circumferential direction around the cavity waveguides.

However, since the diametral acoustic mode in a rectangular cavity has a fixed orientation of pressure and acoustic particle velocity, it produces a non-uniform excitation source of the separated shear layer, resulting in a highly complex three-dimensional flow structure that is challenging to capture experimentally. To address this issue, a three-dimensional Large Eddy Simulation (LES) is performed to capture the self-excited diametral acoustic mode mechanism within the square and rectangular cavity, including the analysis of the unsteady dynamic behavior of the flow field. This simulation provides a better understanding of the underlying physics of the self-excited acoustic resonance phenomenon and can aid in developing more efficient and effective strategies to mitigate the associated noise and structural integrity concerns in industrial applications.