The acoustic resonance of cylindrical cavities

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Abstract

The grazing flow past a cylindrical surface cut-out can develop instabilities that adversely affect the aerodynamic performance of airframe, automotive, and railway components. Such instabilities can be either fluid dynamic, hydroelastic or flow-resonant, depending on whether aeroelastic or acoustic effects contribute to the flow unsteadiness.

The flow past the surface cut-out, or cavity, separates at the upstream edge, forming a shear layer, as shown in figure 1. Provided the cavity streamwise length to depth ratio (L/D) is low, typically $L/D \leq 6$, the shear layer spans across the cavity opening and reattaches on the downstream wall, forming an 'open' cavity flow [1]. For a given inflow condition and geometry, a cavity fluid dynamic instability can manifest itself as limit cycle modes spanning a specific frequency range. The presence of acoustic or aeroelastic resonant modes in an open cavity over the same frequency range can play an important role in mode selection [2] and in phase-locking the feed-back process.

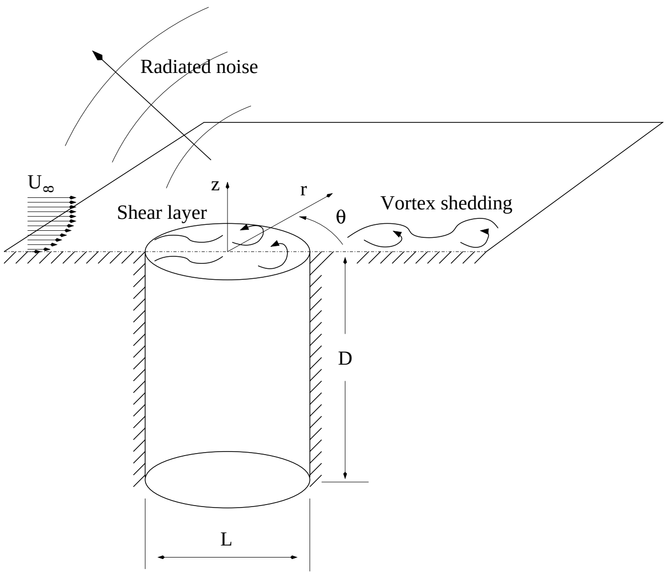

Figure 1: Cylindrical cavity.

An analytical model for the small amplitude acoustic perturbations inside an enclosure with rigid walls is developed from classical linerized acoustics. The method is applied to a $L/D = 0.714$ cylindrical geometry and the normalized mode shapes and frequencies of the first six standing wave modes are given. The results are used to diagnose whether, at a free stream Mach number $M_\infty = 0.235$, coupling is likely to occur between the first two Rossiter modes and the acoustic standing waves, which may lead to a reinforcement of the flow instability.

At the selected test conditions, the method indicates that the second Rossiter mode can couple with the first axial acoustic mode, also known as the organ-pipe mode or the quarter-wavelength mode.

The parametrized analytical solutions developed in this study enable the aero-acoustic engineer to diagnose whether coupling between a given fluid dynamic instability and acoustic resonance is likely to affect a cylindrical cavity component.

References

[1] A. Charwat, J. Roos, F. Dewey, J. Hitz, An investigation of separated flows. Part I: The pressure field, J. Aerospace Sci. 28 (6) (1961) 457–470.

[2] C. Rowley, D. Williams, Dynamics and control of high-Reynolds-number flow over open cavities, Annual Review of Fluid Mechanics 38 (2006) 251–276.

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