Shear layer dynamics of a cylindrical cavity for different acoustic resonance modes

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Keywords: Cylindrical cavity, Resonance, Modal decomposition, Azimuthal, Shear layer

This paper investigate the interaction between the shear layer over a circular cavity and the flow-excited acoustic response of the volume to shear layer instability modes. Within the fluid-resonant category of cavity oscillation, most research has been carried out on rectangular geometries and where cylinders are considered, side branch and Helmholtz oscillators are most common. In these studies, focus is generally restricted to either longitudinal standing waves or to Helmholtz resonance. In practical situations however, where the cavity is subject to a range of flow speeds, many different resonant mode types may be excited. The current work presents a cylindrical cavity design where Helmholtz oscillation, longitudinal resonance and also azimuthal acoustic modes may all be excited upon varying the flow speed. Experiments performed show how lock-on between each of the three fluid-resonances and shear-layer instability modes can be generated. A circumferential array of microphones flush mounted with the internal surface of the cavity wall was used to decompose the acoustic pressure field into acoustic modes and has verified the excitation of higher order azimuthal modes by the shear layer. One of these interior pressure signals was also used to provide a phase signal for averaging flow field measurements of the shear layer acquired using PIV. Observation of the PIV images provides insight into these acoustically coupled oscillations.

1. Discussion

Shear layer driven cavity flows can exhibit several types of features generally described as resonance. The review paper of Rockwell and Naudascher (Rockwell and Naudascher 1978) categorized self-sustaining oscillations into three groups: fluid-dynamic; fluid-resonant; and fluid-elastic. Of these, self-sustaining cavity oscillations which are strongly coupled with resonant waves within the cavity may be classified as fluid-resonant oscillations. To date, within the fluid-resonant category, almost no consideration has been given to higher order acoustic modes which might resonate in cavities. In this paper we are particularly interested in exploring the test case where a number of different types of resonant behavior can be excited depending on flow speed or orifice geometry. In practical cases, such as for aircraft take-off and landing where the flow speed varies, it is important to be able to predict these modes so that mitigation measures can be implemented.

A cylindrical cavity experiment which allows different modes of resonant behaviour to be excited depending on flow speed and orifice geometry has been design and constructed. Specifically, modes falling into the fluid-resonant category, viz., Helmholtz resonance, Longitudinal resonance and Azimuthal resonance, have all been excited by different shear layer oscillation modes. Lock on between these different resonant modes and shear layer excitation has been clearly measured and observed to occur upon adjusting only the flow speed. An azimuthal acoustic modal decomposition was performed and verified the modal composition of the resonances. Phase averaged PIV allowed the coherent structures present in the shear layer to be examined and the interaction between the cavity resonance and the shear layer oscillation to be observed.

Fig. 1 a, b. Schematic of rig illustrating orifice to cylindrical cavity. Also shown is a numerical solution to illustrate a higher order acoustic mode excited by the shear layer.

Fig. 2. Acoustic response inside the cavity as a function of tunnel flow-speed. Superimposed on the plot are the theoretical shear layer modes and also the three sets of fluid-resonant categories investigated.

Fig. 3. PIV results at cavity orifice for excitation of a fluid-resonant oscillation: excitation of the first longitudinal mode, H1, by the first shear layer mode.