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Generation of locked-on flow tones: Effect of damping

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ABSTRACT

The overall objective of this investigation is to determine the effect of variable damping on the pressure response of a deep cavity. The pressure fluctuations arise from coupling between the unsteady shear layer along the cavity opening and a resonant mode of the cavity. The damping of the cavity is tuned to desired values without changes of geometry or other parameters.

The amplitude of the cavity pressure fluctuation as a function of flow velocity is characterized for the first, second and third acoustic modes of the cavity. For each mode, variation of the value of damping over a relatively wide range yields corresponding attenuation of the pressure amplitude. For higher acoustic modes and sufficiently large damping, abrupt decreases of the pressure amplitude occur at threshold values of flow velocity.

The variable damping of the deep cavity does not significantly alter the eigenfrequencies of the system. The peak response amplitude of the pressure fluctuation, however, occurs at a value of Strouhal number that increases with increasing values of damping. Moreover, this peak response amplitude, when normalized by the free stream dynamic head, generally shows a linear variation with the value of damping, for three acoustic modes of the cavity.

The strength of lock-on of the pressure oscillation, as a function of the degree of damping, is evaluated in terms of the coherent and broadband pressure amplitudes. Both amplitudes are attenuated for increased damping; the difference between them, however, remains relatively large (40 dB minimum), thereby indicating well-defined lock-on, even when the amplitude of the spectral peak of the coherent component is substantially attenuated.

1. Introduction

A wide range of engineering applications involving either gas or liquid are associated with flow-acoustic coupling, both for internal and external flows. Selected aspects, most relevant to the present investigation, are addressed in the following.

Tonon et al. (2011) provide an overview of the aeroacoustics of pipe systems with closed branches. Flow-acoustic coupling in a single side branch (deep cavity) attached to a main duct has been addressed by Bruggeman (1987). He defined the overall oscillation characteristics as a function of flow velocity, and interpreted his findings by accounting for radiation and friction effects. Related features are also described in the works of Bruggeman et al. (1989, 1991). Hofmans (1998) employed numerical computations to determine the resonant response of a single side branch, while accounting for various types of damping within the branch.

Ziada and Buehlmann (1992) characterized resonance in a single side branch, where the termination condition of the main duct was different from preceding studies. Use of an absorption silencer in the duct had a substantial effect on the

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oscillation characteristics. A further aspect of the investigation of Ziada and Buehlmann (1992) involved interpretation of acoustic radiation from the side branch into the main pipe, while accounting for various losses in the overall system. They showed, based on the data of Jungowski et al. (1989), that the ratio of the characteristic diameter of the side branch to the diameter of the main duct had a remarkable influence on the peak pressure amplitude; it was maximized when this ratio was small.

All of the foregoing investigations involved a single side branch (deep cavity) connected to a main duct. The focus of the present investigation is on a deep cavity that is exposed to the atmosphere, and the system configuration is similar to that of Dequand (2001). It was demonstrated therein that when the cavity mouth was open to the free atmosphere, large amplitude flow tones could be generated. Yang et al. (2009) characterized the flow tones generated by this type of deep cavity system, for a range of cavity length and depth. Similarly large amplitude flow tones were also attained for the coaxial and tandem arrangements of two (or more) side branches in a main duct, by several researchers including Bruggeman et al. (1991), Ziada and Buehlmann (1992), and Graf and Ziada (2010). Attenuation of these types of flow tones has been addressed by Oshkai and Velikorodny (2013).

For all cases of deep cavities, it is expected that the value of the inherent damping of the resonator will have a pronounced effect on the magnitude of the self-excited oscillation. Despite its importance, the effect of damping on the flow-acoustically coupled oscillations has received relatively little attention. For the special configuration of two coaxial deep cavities, i.e., opposing single side branches, Kriesels et al. (1995) demonstrated that the depth of the cavity could substantially alter the magnitude of the pressure at the dead end of the cavity. They interpreted the enhanced damping at larger depths in terms of thermoviscous effects along the interior wall of the cavity. The effect of cavity depth on pressure oscillation magnitude was also shown by Ziada and Buehlmann (1992) for coaxial and tandem side branch configurations. Slaton and Zeegers (2005) addressed the effects of losses in a coaxial side branch configuration. These losses included thermoviscous losses, radiation losses at higher amplitudes, and losses due to a dissipative resistance-volume device attached to the end of one of the branches. Graf and Ziada (2010) developed a semi-empirical model in order to predict the frequency and pulsation amplitude of flow-excited acoustic resonance in side branches, where radiation losses into the main pipe and the thermoviscous losses along the cavity walls were taken into consideration.

The overall objective of the present investigation is to determine the nature of the pressure response, i.e., unsteady cavity pressure versus flow velocity past the cavity, in relation to the cavity damping, which can be tuned to arbitrary values. Further aspects include the influence of cavity damping on the frequency versus velocity characteristics, the frequency at which peak amplitude pressure response occurs, the nature of the pressure spectra, and the strength of lock-on.

2. Experimental system and techniques

2.1. Overview of experimental system

The major subsystems, which make up the overall experimental system, include the air conditioning and supply system and the actual inlet duct-deep cavity system. The air conditioning and supply system is located in an adjacent room, which is well isolated from the room containing the experimental test section. As a consequence, any issues of noise and vibration associated with the air compressor are avoided.

2.2. Air supply and inflow system

Pressurized air generated by the compressor was stored in a plenum, where it was maintained at a value of gauge pressure of 552–689 kPa (80–100 psig). When the air flowed from the plenum, it passed through a dryer arrangement, then a filter system. It then passed through the isolation wall into the room that contains the experimental test section.

Disturbances from the inlet line valve system were effectively attenuated using a long flexible hose, located immediately upstream of the plenum of the main test section. This hose had a total length of 5 m and an inside diameter of 25.4 mm. Air from this inlet hose exhausted into the main plenum of the test section. All components of this plenum were constructed of Plexiglas. Its interior was lined with foam, in order to preclude the occurrence of acoustic resonances. Moreover, in order to quiet the flow within the plenum, a honeycomb of length 76 mm having 3 mm cells was placed within the plenum. Finally, this very low speed air flow was accelerated in a three-dimensional nozzle, which was connected to the main duct, as shown in Fig. 1.

2.3. Main test section

A zoomed-in view of the main duct-deep cavity system is given in Fig. 1. Details of this system, including all geometrical characteristics, as well as preliminary diagnostics to demonstrate lack of coupling between the acoustics of the deep cavity and the inflow duct, are described by Yang (2005). The duct had internal dimensions of 38.1 mm $\times$ 25.4 mm. It was bounded on all four sides over its entire length of 530 mm, except for one open side, which is depicted in the lower right portion of the plan view of Fig. 1. This open portion of the main duct ensured that the resonance of the deep cavity was decoupled from the main duct. In order to ensure that possible resonances of the main duct were well separated from those of the deep