Prediction of flow induced vibrations of straight ducts taking into account acoustic and turbulent components

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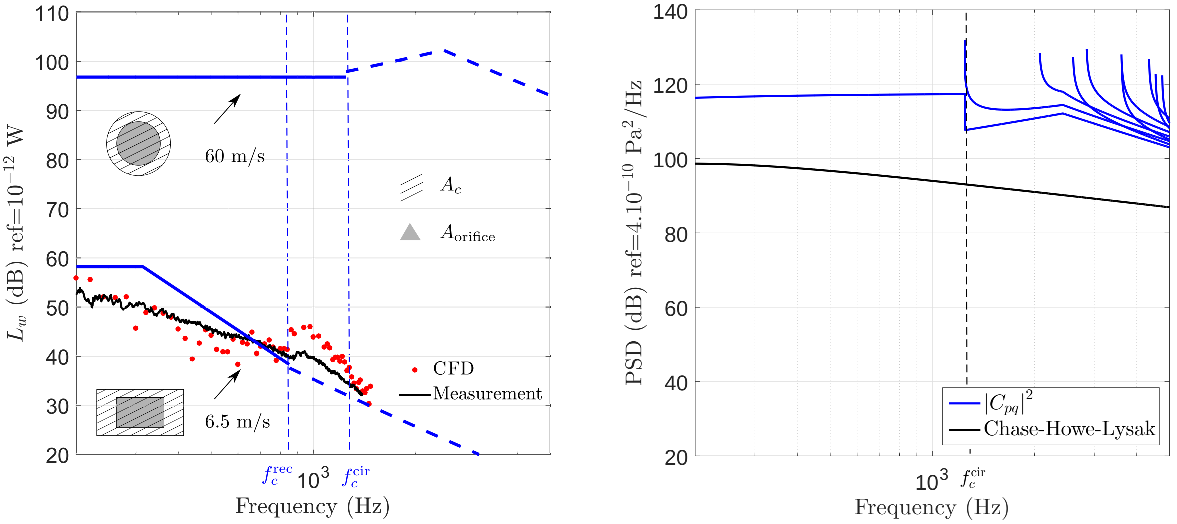
In the ideal case of a fully developed turbulent flow in a straight cylindrical duct with no flow discontinuities, vibrations are generally caused by the wall pressure fluctuations in the Turbulent Boundary Layer (TBL). However, Norton's textbook (see Ch.7 in [1]) emphasizes the importance of considering plane wave and high order modes in the prediction of thin cylindrical pipe vibration. In addition, a study of the vibration response of a straight duct with rectangular cross-section excited by a turbulent internal flow has shown that acoustic waves must be taken into account in the analysis to predict the vibration response [2, 3]. Hence, it appears that the prediction of pipe vibration due to internal turbulent flow gives different conclusions depending on the duct material properties, the cross-section, the frequency range under study and the acoustic energy level associated to a localized obstacle or generated by the turbulent boundary layer itself.

The aim is to provide a numerical tool for engineers to study pipe flow noise and vibration considering both cross-sections, an obstacle or not and a forcing function which takes into account the relative contributions of turbulent and acoustic components. More details about the developed framework can be found in [4]. In this paper, attention is payed on the vibration response of pipes with a circular cross-section. It is assumed that the tested duct of finite length is placed far from a flow constriction (here a diaphragm is considered) inserted in the pipe network.

The acoustic energy is calculated according to scaling laws using the recent development of Kårekull [5]. Just the knowledge of the constriction geometrical characteristics, *ie*, the orifice and the duct cross-section area A_c and A_{orifice} allows to predict the acoustic power. Fig. 1(a) shows the computed acoustic power generated by an orifice for circular an rectangular ducts according to Kårekull work. It is plotted along with previous measurement and CFD calculation using an aeroacoustic analogy for the case of a rectangular duct. The spectrum model allows reliable predictions and it is now extended to the case of a circular duct. Fig. 1(b) shows the corresponding acoustic modal amplitudes $\left|C_{pq}^{+}(\omega)\right|^2$ for a circular flow orifice along with TBL point spectrum calculated with the Lysak fit of the Chase-Howe model at 60 m/s. Two regimes are dissociated: one corresponds to a plane wave propagation until the first duct frequency cut on f_c and the other is associated to high order acoustic modes propagating in the duct.

Finally, the spatial correlation of the forcing function is written on the basis of a sum of an hydrodynamic contribution provided by the Corcos's model and an acoustic part given by the coherence function of high order modes. The prediction of the duct structure vibration is obtained using analytical modal Frequency Response Functions (FRFs) of a simply supported finite duct.



(a)

(b)

Figure 1: Acoustic and turbulence components: (a) acoustic power (in blue) using the recent development of Kårekull compared with CFD and aeroacoustic analogy for the case of a rectangular duct (b) the associated acoustic modal amplitudes $\left|C_{pq}^{+}(\omega)\right|^2$ along with the TBL point spectrum calculated with the Lysak fit of the Chase-Howe model at 60 m/s for the circular case. In (a), continuous and dashed blue lines stand respectively for the plane wave and multimodal propagation.

References

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