CAVITY NOISE

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1 Introduction

The noise radiated by a flow past a cavity has been widely studied during the last fifty years because of its practical interest and because of the variety of theoretical questions that it raises. A complex feedback process sustains coherent oscillations in the shear layer developing above the cavity, leading to important radiated noise. This noise consists of intense discrete and broadband components.

The aim of the present lecture is to analyse this complex equilibrium and to shed light on the competitive or collaborative nature of the different interactions that take place. This is a multi-faceted configuration, insofar as the flow can be viewed as a synthesis of a turbulent shear layer above the cavity, a complex recirculation inside the cavity, turbulent boundary layers on the upstream and downstream walls, and long-wavelength acoustic fluctuations inside and outside the cavity.

The problem of cavity noise is one of the interaction of the acoustic and vortical modes. Chu and Kovasznay [30] have shown how the general compressible Navier-Stokes equations can support three modes of fluctuations, namely the vortical mode (or hydrodynamic mode since this is the sole mode supported by the incompressible equations), the acoustic mode, made of upstream and downstream propagating waves, and the entropy mode, related notably to thermodynamics phenomena. The amplitude of the self-sustained oscillations arising in cavity flows, and of the corresponding noise emission are determined by the acoustic-vortical nonlinear interaction, although other interactions are possible and can modify significantly the final solution. The energy balance can also be influenced by the presence of an acoustic resonator in the immediate vicinity of the shear layer-edge interaction, as demonstrated by Nelson *et al.* [134]. The vortex sound theory has helped to cast light on the interactions of the acoustic and vortical modes. The flow interacting with solid surfaces generate vorticity, feeded by the mean flow, eventually by vortical-vortical interactions (like pairing events), and by the transfer of acoustic energy into vortical perturbations, notably in the receptivity problem near the upstream edge. The vortical flow induces in turn acoustic waves, whether during the impingement process, or by triggering a resonance mode of the cavity or of the tunnel (Helmholtz resonance, standing waves like depth-mode, longitudinal-mode, or spanwise-mode). The energy exchange thus arises in both directions. Acoustics can generate vorticity, and the transfer is from the acoustic mode toward the vortical mode. This is the case near the upstream edge, where the imposition of the Kutta-Joukowski condition absorbs acoustic energy [76, 79]. This behaviour is coherent with the Bechert-Howe theory of dissipation of acoustics by an edge at low Helmholtz numbers [8, 76]. The imposition of an unsteady Kutta condition at an edge, or equivalently the rate of vorticity shedding converts a part of the acoustic energy into kinetic energy. On the other side, vorticity can generate acoustics, and the transfer is from the vortical mode toward the acoustic mode. The deformation and acceleration of the vorticity during the impingement process is essentially responsible for this transfer. Generally, the net transfer is in favour of the acoustic mode, so that we talk about cavity noise, as the undesirable consequence of the flow over a cavity. There is a case where the net transfer is in favour of the vorticity: the acoustic liners. The honeycomb material backed by a perforated screen behaves like numerous Helmholtz cavities under grazing flow, and can attenuate incident acoustic waves, generated for example by the fan of aircraft engines.

1.1 Historical notes

The first studies on cavity noise concerned aeronautic applications in the 1950-1960's [80]. For the military aircrafts, the weapon bays experience flow-induced oscillations which can excite the vibrational modes of the aircraft structure. They can represent about 30 % of the total drag of the plane. The rectangular cavities that are studied have large dimensions and are relatively shallow. The speeds are highly subsonic to supersonic. The need to explore lower velocities appears in the 1970's because aircraft wheel wells have been seen to be an important source of aerodynamic noise in the landing approach, and during take-off of airplanes.

The application field is then enlarged to the high-intensity oscillations which occur in numerous resonant systems under grazing flow. The resonant cavities have various shapes, for example, the cavities that form the different stages of a compressor or a combustion chamber [92], the T-junctions or closed side-branches in duct networks, the excavations in the air or water pipes for gaz transport, or steam circuits in power plants (see the work of the team of Hirschberg [22, 146, 101] and its lecture *Self-sustained oscillations of internal flows* [71]), Numerous authors have investigated the interactions betwen the vortices shed in the main flow and acoustic resonances. Depending on its geometrical charateristics, the cavity can behave like an Helmholtz resonator [75, 133]. Burroughs and Stinebring [25] showed that an Helmholtz resonance can occur in water. In this particular case, the high intensity and the low frequency of the oscillations yielded deformations of the cavity walls. The fluid-structure interaction can thus be determinant in hydrodynamic applications. Similar self-sustained oscillations can occur in wind or water tunnels with slotted walls [93, 12], which can disturb the measurements. At a larger scale, unsteady hydrodynamic phenomena have also been observed in canal locks, or in the harbour entries [125].

Another important fied of application is aero-optics. The optical windows of in-board lasers, or other optical instrumentations, can not be closed by a glass or a plexiglas plate which would disturb the measurements (distorsions, heating ...). However, the oscillations induced by the so-formed cavity can also generate perturbations, and the understanding of the mechanism leading to oscillations is