FLOW OVER A PARTIALLY LIQUID FILLED CAVITY

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Abstract Experiments have been carried out to investigate the effect of liquid cavity filling on the behavior of the gas flow over a flat plate cavity. PIV measurements in the gas phase reveal that cavity filling can affect vortex shedding in the cavity mouth. Shear layer vortices can break-up into smaller vortices, thereby losing their periodic interaction with the aft wall and, hence, their sound producing potential. Expected is that this is one of the mechanisms causing sound mitigation in corrugated pipes with liquid addition, observed in literature.

INTRODUCTION

Corrugated pipes are used in many applications because of their global flexibility, while maintaining local rigidity. They can be seen as a combination of many subsequent axissymmetric cavities in a tube. Some problems do arise when using corrugated pipes in different applications such as flow induced vibrations and sound production. A mixing layer is formed over each individual cavity and in certain conditions vortices are shed in the cavity mouth that interact with the trailing edge, thereby producing sound and eventually structural vibrations. Recent studies [1, 2] have shown that the addition of small fractions of liquid can cause attenuation of the noise production. Several mechanisms have been proposed to be causing this effect, but there is still limited knowledge when it comes to their individual contributions. One of those mechanisms is the filling of the cavity with liquid, that can alter the mixing layer behavior and can possibly lead to sound mitigation. In this experimental investigation the mixing layer over a flat plate cavity with different liquid filling degrees has been studied. The results can be used to interpret the contribution of cavity filling as a sound mitigating mechanism in corrugated pipes.

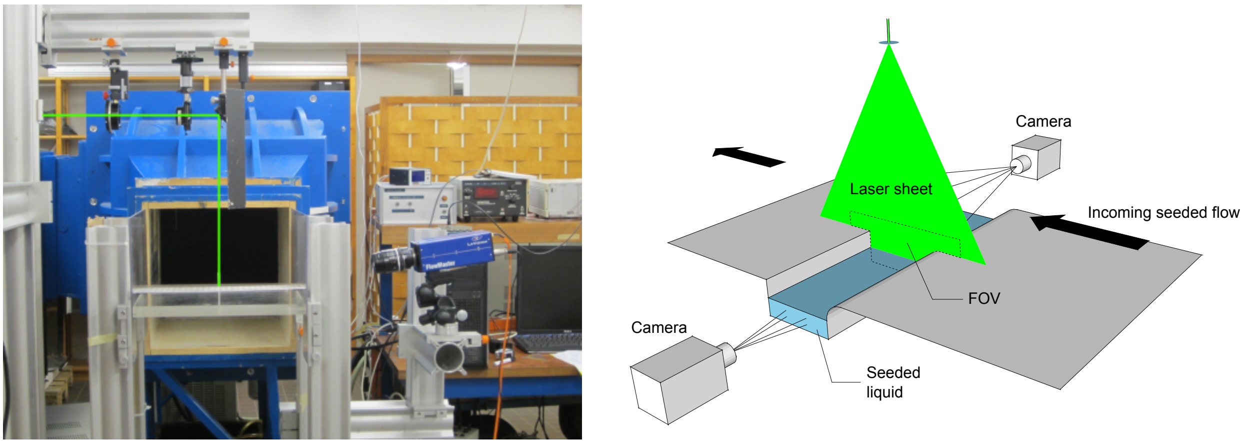

Figure 1: PIV setup, as used in the experiments, from behind the cavity (left) and a schematic drawing of the set-up(right).

EXPERIMENTAL SETUP

The mixing layer behavior has been studied using velocity data obtained from planar PIV measurements on a flat plate cavity, placed in a wind tunnel. The experiments were carried out at the Low Speed Laboratory of the TU Delft. The windtunnel outlet is 0.4mx0.4m, a maximum free stream velocity of 35m/s can be achieved, having a turbulence level <1%. The cavity, with a length over depth (L/D) ratio of 2, had a curved leading edge and a sharp trailing edge and was located 150mm from the leading edge of the flat plate. The incoming boundary layer (BL) characteristics were determined using HWA measurements. Experiments were carried out over a range of incoming boundary layer thicknesses ($83 < \frac{L_{cav}}{\theta} < 235$). Cavity length based incoming Reynolds numbers were varied between 2.7×10^4 and 5.3×10^4. For the turbulent cases a trip wire was added 80 mm upstream of the cavity. Two series of PIV measurements were carried out. A 1-mm thick laser sheet illuminated the tracer particles with a mean diameter of 1μm. During the first measurement series a 1MP CCD camera (LaVision Imager Intense) was used with a 55mm Micro-Nikkor objective. Image pairs were recorded at 3.4Hz, with a total of at least 2000 frames per measurement series. For the second PIV measurement series, time-resolved planar PIV was carried out simultaneously in the gas flow and in the liquid inside the cavity. Image pairs were recorded at 1kHz, using two Photron Fastcam APX cameras at 512x1024 pixels, with 105mm Micro-Nikkor objectives. For the liquid side 15μm FLUOstar fluorescent tracers were used, combined with a 570nm LP filter to minimize the reflections of the laser light on the liquid surface.

RESULTS

From the obtained velocity fields the vortex shedding behavior in the mixing layer spanning the cavity has been identified. The empty cavities show a Kelvin-Helmholtz like vortex shedding behavior as expected from the incoming BL. The internal cavity flow consisted of a large recirculation cell filling the entire cavity and its structure was comparable to what was found in literature by e.g Koschatzky and Öszoy [3, 4]. Upon liquid filling the recirculation cell changed in size and structure, depending on the water surface behavior. At higher incoming Reynolds number flows, the water surface showed a stable dent at the trailing edge, causing the recirculation cell to become skewed. For the lower Reynolds number the water surface behaved more like a solid wall, leading to a recirculation cell only shrinking in size upon filling. This recirculation cell was found to be initiating vortex shedding in the mixing layer by introducing small disturbances to it. Above 90% filling no vortex shedding was observed at all. In some cases, filling the cavity with liquid caused the vortices in the cavity mouth to break-up into smaller vortices (figure 2), thereby destroying the periodicity of the vortex-wall interaction and the possible sound production. Expected is that this is one of the mechanisms causing sound mitigation in corrugated tubes. From time-resolved measurements it appeared that the vortex break-up was an alternating process, switching in one experiment from break-up to no break-up of the shed vortices. With increased filling degree, a decreasing trend was seen in the mixing layer linear growth rate. For the Re 2.7×10^4 case the growth rate decreased with 25% when filling the cavity to 50%.

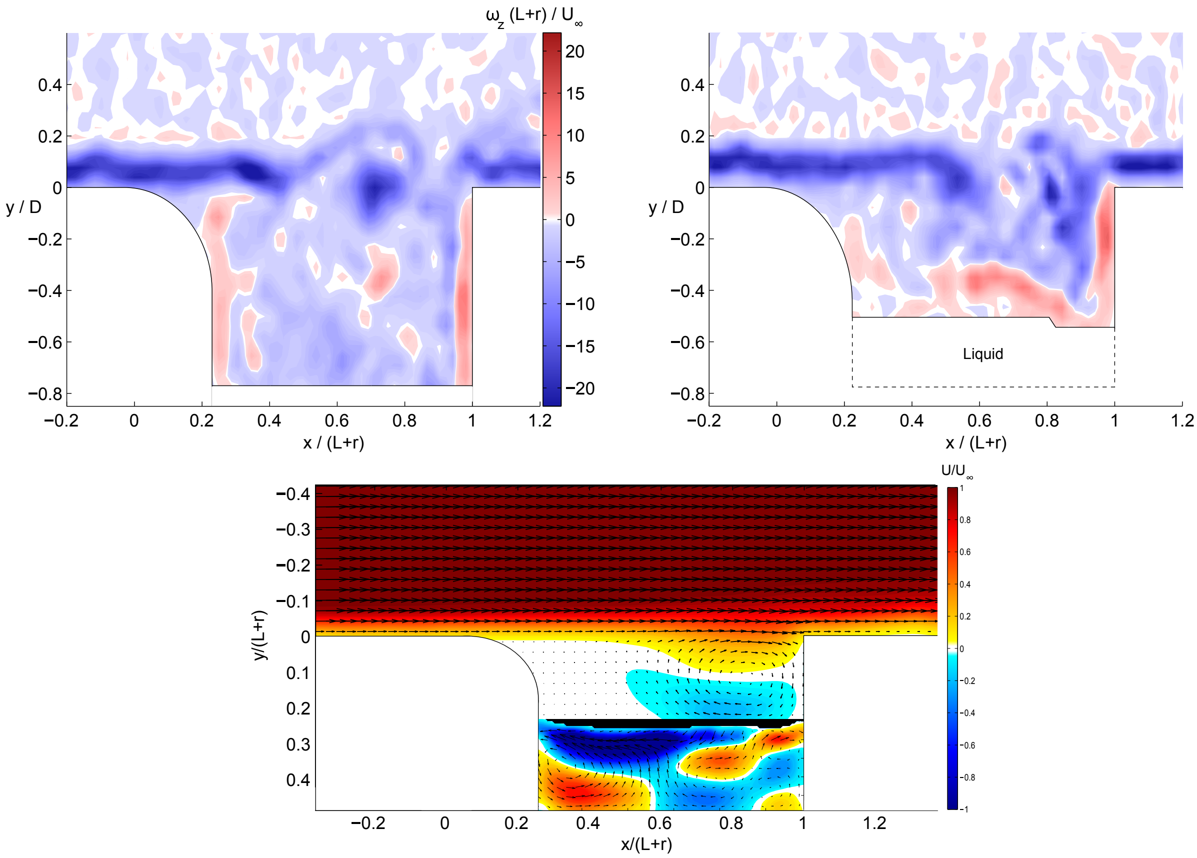

Figure 2: Instantaneous normalized vorticity distributions for and empty cavity (top-left) and a 50% liquid filled cavity (top-right) at Re = 4.0×10^4. Bottom figure shows combined average streamwise velocity contours and average velocity vectors in the gas and the liquid inside the cavity for Re = 2.7×10^4; one in every four vectors at the liquid and one every two at the gas-side are shown, velocity range at liquid side is 1×10^{-4} times that at the gas side.

References

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