AEROACOUSTICS OF SUBSONIC JETS

Christophe Schram, Belgium
Supervisors: Prof. M.L. Riethmuller (VKI) & Prof. A. Hirschberg (TU/e)
Promoters: Prof. M.E.H. van Dongen (TU/e) & Prof. G. Degrez (ULB)

The present work aims at a better understanding of the hydrodynamic mechanisms through which noise is produced in the exhaust jets of the by-pass engines that equip civil transport aircrafts. A key point in such an aeroacoustical problem is the understanding of the dynamics of coherent structures and of their interactions leading to sound production. In particular, the pairing of vortex rings is here considered, being known as a dominant phenomenon responsible for noise generation in subsonic jets.

Experimental and theoretical approaches are combined in this study. The first one is used to gather detailed information about the vortex pairing through Particle Image Velocimetry (PIV) measurements. The second one implies the application of an acoustic analogy known as Vortex Sound Theory to predict the noise emitted by the vortex pairing modeled with the help of the experimental data.

Aero-acoustical analogies such as the Vortex Sound Theory, allow a reduction of the impact of errors in the description of the flow on the calculation of the acoustical field. Two different aero-acoustical analogies published until now, namely Powell's and Möhring's analogies, have been considered. Their efficiencies have been evaluated by their application to analytical models of vortex pairing. It was shown that the difference in robustness between Möhring's formulation and Powell's formulation is attributable to the reinforcement of the assumptions of conservation of the flow invariants.

On the basis of these results, a new conservative formulation of Vortex Sound Theory has been obtained for axisymmetrical flows. A series of tests applied to analytical models of vortex ring pairing demonstrates that the effect of different kinds of errors on the sound prediction is reduced by more than one order of magnitude compared to the results obtained using the original formulations of Vortex Sound Theory.

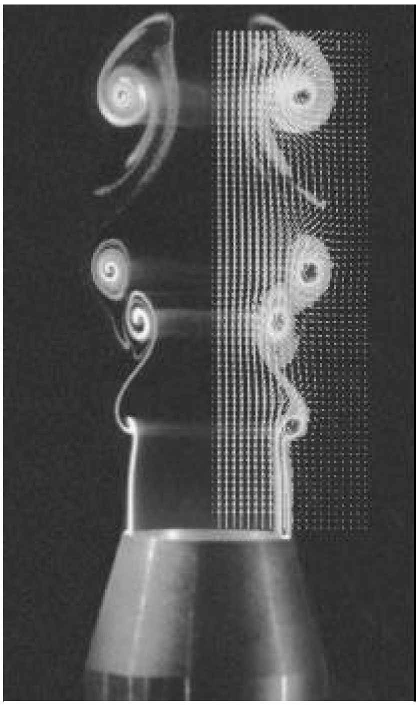

Figure 1: Smoke visualisation (left) and PIV measurement (right: velocity and vorticity fields) of vortex pairing (U_0 = 5 m/s ; f_e = 114 Hz ; u'_e / U_0 = 0.25 %).

An experimental setup has been built for the investigation of the dynamics of a single subsonic circular air jet (D = 0.04 m ; Ma = 0.01 – 0.1 ; $Re = 10^4 - 10^5$) submitted to an acoustic excitation. The response of the jet to the excitation can be systematically observed using smoke flow visualisation (Figure 1), within a range of amplitudes and frequencies of the excitation ($u'_{\text{exc}} / U_0 = 10^{-3} - 2.10^{-1}$; $Sr_D = f_{\text{exc}} D / U_0 = 0.1 - 3$). The parameters of excitation leading to stable vortex pairing are determined for several jet outlet velocities.

Specific developments of the PIV technique, including the synchronization of the pulsed laser and of the digital camera with the acoustic excitation of the jet, allow the measurement of phase-locked and stroboscopic (pseudo-time resolved) series of velocity fields, from which the vorticity is computed (figure 1). The data is post-processed using a wavelet-based algorithm in order to automatically detect the vortices, therefore allowing a statistical characterization of the vortex rings.

The new conservative formulation of Vortex Sound Theory is applied to PIV data obtained on vortex pairing in the excited jet flow. We show that a meaningful sound prediction cannot be obtained applying the original formulations of the Vortex Sound Theory to our experimental data. It is shown that some formulations of the theory improve the robustness of the sound prediction. The sound prediction that is obtained by means of the new conservative formulation is meaningful and shows some significant differences between the sound produced by the jet column and the shear layer modes of pairing. The differences are related to the importance of the deformation of the vortex cores during merging that is observed for each pairing mode.