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EXPERIMENTAL CHARACTERISATION OF AERO-ACOUSTIC SOURCES IN ENCLOSURES

Y. Knapp*, L. Jourdan*, E. Bertrand*, J.P. Guibergia**

* FLUIDATA, IMT - Technopole de Chateau Gombert, 13451, Marseille, France

** ESM2, IMT - Technopole de Chateaau Gombert, 13451, Marseille, France

Tel.: +33 (0)4 91 05 43 81 / Fax: +33 (0)4 91 05 45 18 / Email: fluidata@marseille-innov.asso.fr

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ABSTRACT
The present study aimed at using Powell's [1] formulations of aerodynamic sound generation, expressing aero-acoustic source strength in terms of vorticity, to quantify aerodynamic sound generated in enclosures. Therefore, a technique of whole field velocity measurements called Particle Image Velocimetry was used to map the instantaneous velocity distribution in the casing of model. This instantaneous flow fields are differentiated twice to obtain the vorticity field, and the Powell's source term is directly computed from these measurements. The differentiation schemes are optimised to reduce cumulative errors. The main advantage of this technique is to perform aerodynamic measurements to approach acoustic problems, therefore giving the possibility to test modifications and judge their effects on both the flow and acoustic field.

1 - INTRODUCTION

In 1964 Powell [1] postulated that the origin of aerodynamic sound might be attributed to the process of forming eddies or vortices. Howe [2] reformulated Lighthill's theory for low Mach number flows in terms of Powell's concept of vortex sound and associated the aerodynamic sound sources with certain regions of the flow where the total vorticity vector $\vec{\omega}$ is non vanishing. For vortical regions located in free space, Howe reformulated Lighthill's wave equation to yield:

$$\frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} - \nabla^2 p = \rho_0 \vec{\nabla} \cdot \left(\vec{\omega} \times \vec{V}\right)$$

The equation illustrates that the sources of aerodynamic sound can be easily located if one can have access to the instantaneous velocity field This points out the main advantage of this theory over the one proposed by Lighthill. As a matter of fact the latter theory specifies the source term in terms of flow properties which are not measurable or calculable. Howe's analysis has therefore been successfully applied to a range of complex problems of sound generation in inhomogeneous flows.
Recent advances in experimental fluid mechanics provided the scientist with very powerful whole-field velocity measurement tools: Particle Image Velocimetry. The principle used here for the velocity estimation consists in determining the displacements of tracer particles illuminated by a flashing light sheet. Digital recording of tracer locations and the use of high speed personal computers for the correlation calculations are the tools that easily provide the temporal and spatial behaviour of the flow (for more information see Raffel et al [3]). Post processing of the information can than be applied for the determination of flow statistics or here the determination of acoustic source terms.
When confronted to complex geometries generating complex and multiple sources of aero-acoutic sound, a technique like this provides a very simple solution for rapid location and ranking of such sources. The modification of the design can than be implemented and verified in the same way. Because of the reduced modifications needed to perform such measurements, it can also be used on real objects where the use of antennas are often difficult.

2 - EQUIPMENT AND FACILITIES

2.1 - Experimental setup

All experiments were carried out in on a test bench at Ecole Supérieure de Mécanique de Marseille. The description of this facility is given in Fig 1.

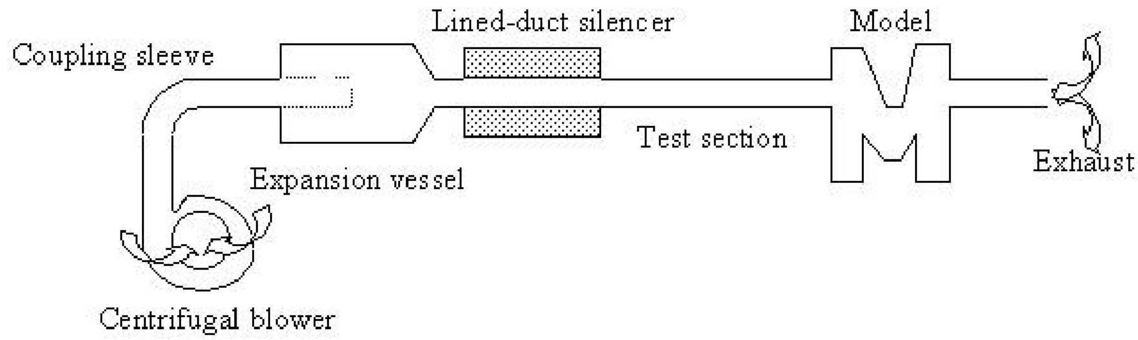

Figure 1: Experimental setup.

The main component of the setup is a centrifugal blower that can deliver up to 2900 Pa at 2900 rpm. This insures velocities up to 68 m/s in the 0,0123 m^2 output section and insures low noise operation at low flow rate. In order to minimise acoustic and vibration contamination of the experimental setup, the centrifugal blower unit was uncoupled form the duct by means of a flexible coupling sleeve. A quieting vessel was also placed downstream from the blower in order to break large turbulent structures and acoustic wave propagation. The output of this vessel was fitted with a 1 m long lined duct silencer filled with acoustic foams of different cutoff frequencies.
The experiments could be performed either in a transparent 1,2m long, S = 95 ×69 mm^2 rectangular test section or in a heater unit model placed downstream of this test section.

2.2 - PIV measurements

The instantaneous velocity fields were determined by means of a Insight PIV system from TSI Inc. In this system a high resolution digital camera is used to record image pairs of the flow illuminated by a pulsed Yag laser sheet. The images are buffered at 30Hz frame rate on 1Giga byte RAM of a bi-Pentium personal computer before disk storage or processing. The images were transformed into velocity information by an optimised correlation process (Hart [4]) at an average rate of 1000 vec/s. In order to reduce cumulative errors in the post processing, the following formula was used for the vorticity:

$$\omega_{i,j} = \frac{\Gamma_{i,j}}{4\Delta x \Delta y}$$

where $\Gamma_{i,j}$ is the circulation of the velocity around the point (i,j) and Δx, Δy are the spatial steps respectively in the longitudinal and transversal direction. The differentiation scheme for the divergence estimation was adapted to forward, backward centre or least squares depending on the presence of neighbour vectors.

3 - RESULTS

On figure 2 is given a typical experimental result obtained when a diaphragm (1/2,46 aspect ratio) is placed in the test section. The first figure shows the geometry used in this experiments. The second shows greyscale levels of the average velocity magnitude field characterised by a disymmetrical jet with a large re-circulation zone. The third figure shows greyscale levels of the average vorticity field mainly characterised by two vortical regions located on the sides of the jet, close to the diaphragm, and representative of the shear layers. Finally, the fourth figure shows greyscale levels of the average acoustic source term. The greyscales show two main source regions, one located close to the diaphragm in the core of the jet and the second further away from the diaphragm in a section where the jet hits the upper wall of the test section. When compared in intensity it is clear that the second zone shows higher levels than the first one, making this region of particular interest when trying to reduce the noise propagated downwards with the flow. These simple observations could be made and corrections could be proposed on most observed fields in the case of the heater unit model.

4 - OUTLOOK

As an extension of this technique, the source field can, for example, be integrated in order to provide a pressure source level useful for acoustic propagation calculations (Thompson et al [5]). Moreover when the flow field is nearly two-dimensional, steady as well as incompressible the pressure field can be estimated through the numerical integration of the steady Navier-Stokes equations in two dimensional form with reference to an initial measured pressure.

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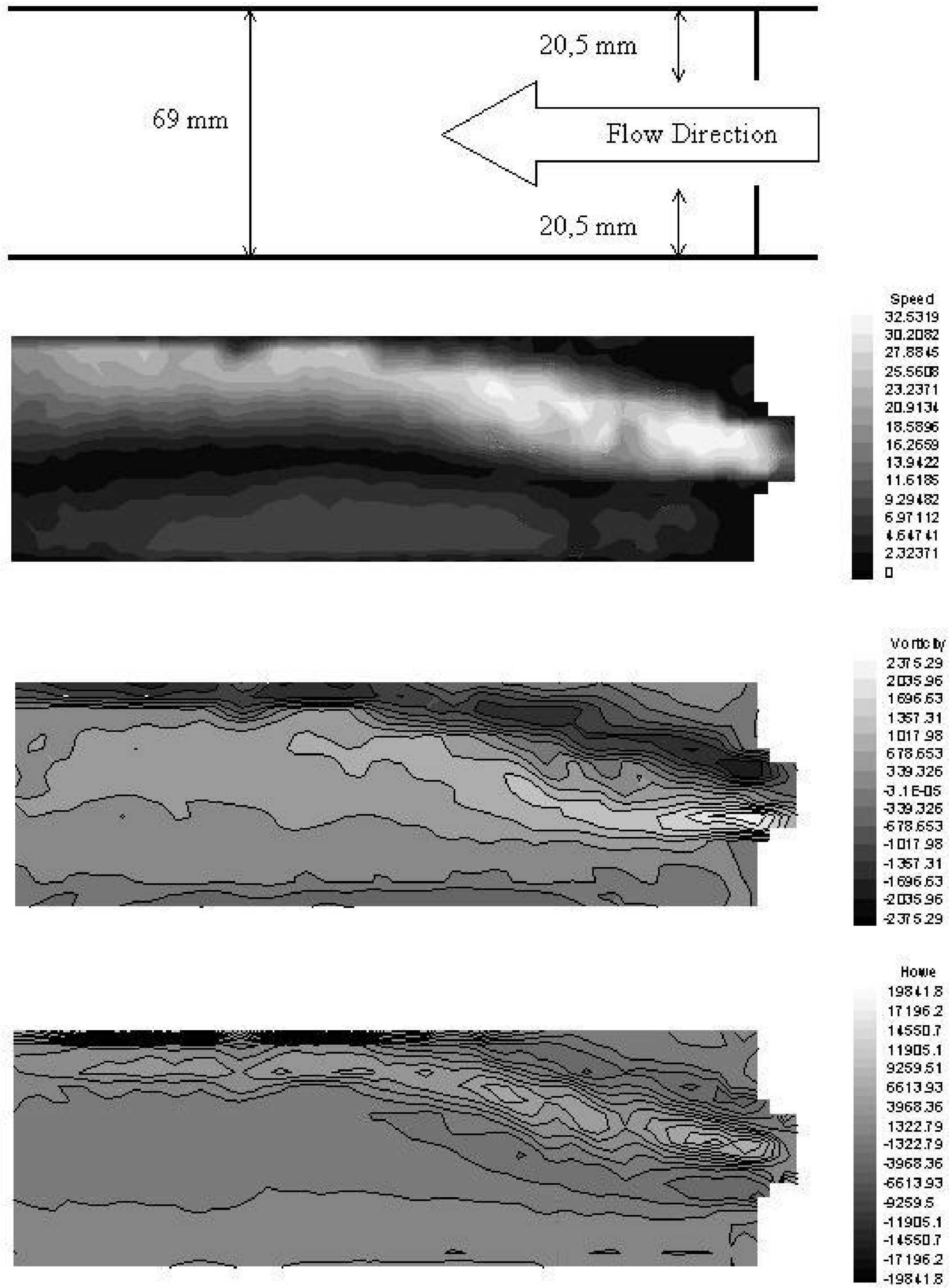

Figure 2: Experimental results.