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Technical Note

Insulation room for aero-acoustic experiments at moderate Reynolds and low Mach numbers

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ABSTRACT

A non-expensive insulation box for aero-acoustic experiments at moderate Reynolds numbers $Re < 2 \times 10^4$ and low Mach numbers $M < 0.2$ is presented. Its performance is evaluated with particular attention to unwanted noise sources inherent to the flow facility. Objective acoustic parameters of the insulation box are assessed.

1. Introduction

The current technical note results from the need to perform aero-acoustic experiments in an ordinary laboratory room equipped with a flow facility. The flow facility consists of compressed air circulating in a uniform tube with diameter 1 cm for which the volume flow rate can be imposed by means of a pressure regulator (Norgren type 11-818-987) and a manual valve. The oil-injected rotary screw compressor (Copco GA7) is isolated in a separated room. The geometries and volume flow rates of interest are such that studied flows are characterised by moderate Reynolds numbers $Re < 2 \times 10^4$ and low Mach numbers $M < 0.2$. Sound frequencies of interest are less than 10 kHz.

The presence of the pressure regulator and airflow circuit in the room is a source of constant broadband background noise, which cannot be filtered out using basic signal processing techniques since it affects all frequencies. Additional constant noise sources are due to the experimental procedure such as computers ventilation noise during data acquisition. Besides unwanted noise sources inherent to the airflow facility or experimental procedure, several punctual and random unwanted noise sources are related to inside activities of colleagues or outdoor activities of passengers or traffic. Consequently, instead of isolating individual noise sources it has been chosen to integrate a non-expensive experimental box in the ordinary room which is suitable for aero-acoustic experiments for flows in the range of interest and serves as an insulation room.

In the following, the design of the insulation box is outlined and its performance is evaluated in terms of insulation and quantitative objective acoustic parameters. The design of the box is successful in case noise produced during aero-acoustic experiments at moderate Reynolds and low Mach numbers can be studied in acceptable flow and acoustic conditions.

2. Design and instrumentation

The box is inserted in an ordinary room with no acoustical treatment of volume 49.8 m^3 and dimensions $4.45 \times 4 \times 2.80$ m, length × width × height. Due to the location of windows, entrance door, space required for experimental material and instruments (such as the settling chamber for flow experiments) and manufacturing issues, the external dimensions of the box are reduced to $2.07 \times 2.10 \times 2.14$ m, length × width × height. A two-dimensional spatial overview of the ordinary room and insulation box is given in Fig. 1a.

The insulation box is built in rigid flat wooden fibre board insulation panels with thickness 2.5 cm to which acoustic foam (SE50-AL-ML, Elastomeres Solutions) with thickness 5 cm is added. The foam consists out of a basis layer of PVC (polyvinyl chloride 5 kg/m^2) to which PU ether (polyurethane) is added. Therefore, the final insulation panels of the insulation box are three layered – wood, PVC, PU ether – with a total thickness of 7.5 cm as illustrated in Fig. 1b. The foam absorbs frequencies in the range from 100 up to 10 kHz which is 'a priori' suitable for broadband noise sources such as pressure regulator and PC ventilator. The efficiency of the acoustic foam depends on the noise frequencies. Characteristics of the insulation box are summarised in Table 1.

Three trapdoors allow access for instrumentation cables. In addition, trapdoors can be used to insert the nozzle to be studied. Trapdoors are made of the same rigid wood panels as the box and

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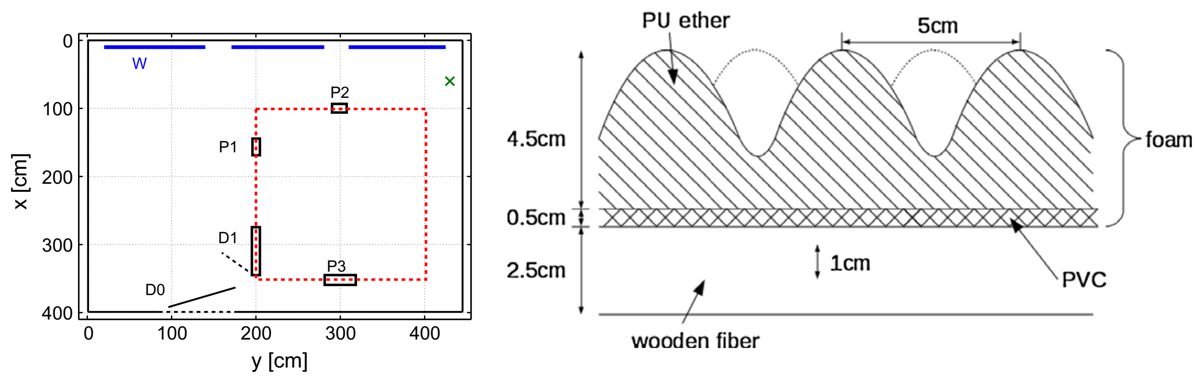

(a) room overview (b) panel section

Fig. 1. (a) Two-dimensional spatial overview of experimental room without acoustical treatment with entrance $D0$, room windows W, compressed air supply ×, insulation box (dashed rectangle) equipped with 3 trapdoors P and door access $D1$. (b) Illustration of a section of the three-layered insulation panel.

Table 1
Relevant insulation box characteristics. Internal dimensions correspond to length, L_x × width, L_y × height, L_z. Corresponding values of the absorption coefficient of the foam α_f for different frequency ranges are indicated [1].

	Values and range	
Internal dimensions	L_x = 1.92 m, L_y = 1.95 m, L_z = 1.99 m	
Internal volume, V	7.45 m^3	
Internal wall surface, S	22.9 m^2	
Absorbing foam (Elastomeres Solutions) (SE50-AL-ML)	98% (α_f = 0.98) 80% (α_f = 0.8) <80% ($\alpha_f \leqslant 0.8$) (linear increase)	2500 < F < 10,000 Hz 1000 < F < 2500 Hz 100 < F < 1000 Hz
Wall thickness	7.5 cm	

have internal dimensions 20 × 20 cm, 20 × 20 cm and 70 × 70 cm. The trapdoors are placed at middle panel height and their positions are indicated in Fig. 1a. A wooden access door of internal dimensions 70 × 200 cm (width × length) and thickness 4.5 cm, is installed to allow access inside the box for setting up the instrumentation. Acoustic foam is added to trapdoors and access door as well.

Besides insulation from outdoor noise sources, the presence of acoustic foam intends to avoid acoustic volume resonance frequencies which depend inversely upon the characteristic lengths of the resonating volume, indicated $L_{x,y,z}$ in Table 1.

Finally, note that, if required, the whole structure can be dismounted and remounted.

3. Performance and discussion

In the following, the flow and acoustic performances of the insulation box are evaluated for the aimed range of Reynolds and Mach numbers.

3.1. Flow performance

Confinement is known to influence the flow [13,6]. The influence of the reduced volume of the box on the flow is studied for a typical nozzle geometry of interest such as a free jet issuing from a round nozzle with diameter $d \leqslant 25$ mm [15]. The nozzle is placed central in a wall panel so that the degree of confinement is similar in all directions.

Jet development involves jet spreading. A spatial overview of the geometrical maximal jet spreading angle $\theta(x,y)$ is given as:

$$\theta\left(\frac{x}{y}\right) = \arctan\left(\frac{x}{y}\right), \tag{1}$$

with streamwise direction x and transverse direction y. The origin ($x = 0$, $y = 0$) is taken at the centre of the nozzle's exit. Based on a typical value of $d \leqslant 25$ mm and a far field expansion angle of $\theta = 9°$ it is seen that jet development can be studied in the near and far field up to $\geqslant 80$d [13]. Consequently, the dimensions of the insulation box are satisfying with respect to jet development experiments.

Besides jet spreading, confinement is known to affect momentum conservation [13,6]. The momentum constraint M/M_0 is expressed as:

$$\frac{M}{M_0}\left(\frac{x}{d}\right) = \left[1 + \frac{16}{\pi K^2}\left(\frac{x}{d}\right)^2 \frac{A_0}{A_r}\right]^{-1}, \tag{2}$$

with tube exit diameter d, tube exit area $A_0 = \frac{1}{4}\pi d^2$, jet centreline distance downstream the tube exit x, A_r cross-sectional area of the room at a given x/d-location, total momentum M_0, local jet momentum M and centreline decay constant K. Thus to first order, the local momentum M in the jet-like part is diminished as x/d increases. Therefore, Eq. (2) can be used to estimate the return of momentum in the jet for given decay parameter and room size. A typical value of the decay parameter for a nozzle with exit diameter $d = 25$ mm yields $K = 5.9$ [15,5]. The two-dimensional cross-section of the box yields $A_r = 3.88$ m^2 using dimensions given in Table 1. The resulting momentum constraint M/M_0 is illustrated in Fig. 2. The streamwise distance is expressed with respect to the streamwise length L_x instead of to the nozzle diameter d, which facilitates interpretation regardless of the diameter d. It is easily seen that for the cross-section A_r a momentum loss in the jet smaller than 10%, 20% and 30% corresponds to streamwise positions of 45%, 65% and 85% of the streamwise length L_x. As a reference also values for half and twice the cross-sectional area A_r are shown, indicating that the streamwise extent is increased with 20% for 2 × A_r and decreased with about 15% for $A_r/2$. Consequently, the current dimensions are judged to offer a good balance between cross-sectional area and momentum constraint since for $d \leqslant 25$ mm jet development can be studied up to $x/d \geqslant 36$ for $M/M_0 \geqslant 0.9$.

3.2. Acoustic performance

An omni directional microphone Bruel & Kjaer (type 4192) with associated pre-amplifier (B&K 4165) and additional amplifier ($0 \leqslant G \leqslant 50$ dB) and power supply (B&K 5935L) is used to perform sound measurements in the untreated room and in the insulation