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Design and Construction of a Silent Wind Tunnel for Aeroacoustic Research

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Abstract

The anechoic chamber of "hepia - Genève" was modified with the purpouse to host a removable wind tunnel for aeroacoustic research. This paper describes in detail the design and construction of this small scale, low Mach number, silent wind tunnel. Special attention is given to a detailed description of the technical challanges faced.

1 Introduction

Due to the growing interest in aeroacoustics from the side of *"hepia - Genève"* (Haute école du Paysage d'Ingénierie et d'Architecture de Genève - hereafter *hepia*), its pre-existing anechoic chamber was modified in order to host a wind tunnel which can be used for aeroacoustic research. The anechoic chamber, still having to be used for classical acoustic measurements, could not host a permanent facility. A choice has been made to design and construct a removable wind tunnel inside the anechoic chamber.

2 Scope of the work

This paper presents the design and the construction of a small-scale, low Mach number and silent wind tunnel for aeroacoustic research. The presented work was realized in the anechoic chamber of *hepia*. The technical challenge of this project rises due to the fact that any new installation in the anechoic chamber should not prevent its further use for purely acoustical measurements. This led to the choice of a silent wind tunnel that does not introduce relevant structural modifications to the anechoic chamber and that can be easily removable.

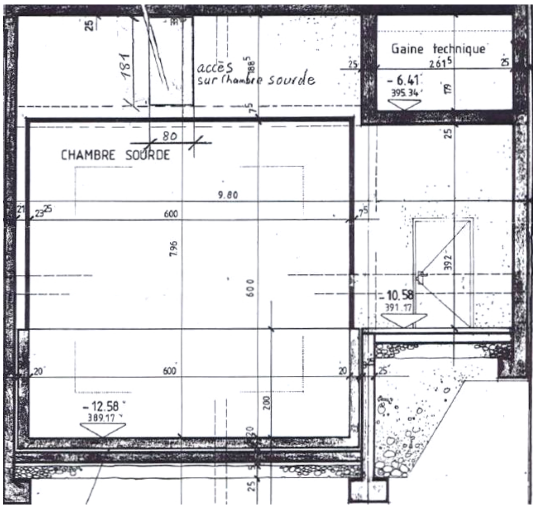

Figure 1: Schematic drawing of the hepia anechoich chamber.

The silent wind tunnel test section is an open test section where flow is provided by an horizontal square jet. The open jet test section is particularly suitable for acoustic testing because the surrounding plenum chamber can be equipped with acoustc linings [2]. In fact, the test section is positioned inside the anechoic chamber, so that aeroacoustic experiments can be performed with a very low background noise

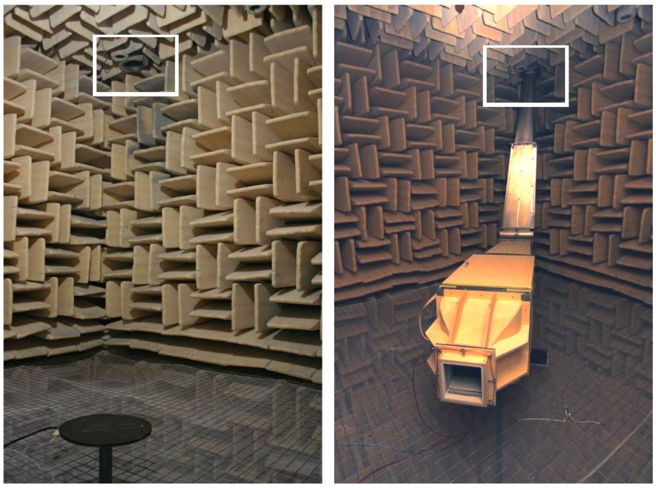

Figure 2: Internal pictures of the *hepia* anechoic chamber. The left figure shows the empty chamber. The right figure shows the wind tunnel setup inside it. The figures highlight the aperture used for the ventilation of the room.

level.

3 The *hepia* anechoic chamber

The *hepia* anechoic chamber, presented in Fig. 1, is a 6 m side cubic chamber lined with sound absorbing wedges (prisms 860 mm long) on the walls, ceiling and floor. The chamber is mounted inside a room that is located underground, to minimize the noise transmitted from the surroundings to the anechoic chamber. Several omega-shaped springs suspend the chamber with respect to the room where it is housed and prevent acoustic-vibrational coupling of the two structures. Above the ceiling of the anechoic chamber, an empty space exists, providing room for technical inspections and for housing a ventilation system. This system is used to blow air from outside into the test chamber, with the purpose of reducing the moisture level in the acoustic facility. The ventilation system discharge (highlighted by the white square in the left picture of Fig. 2) is a 200 mm circular aperture placed near the upper corner of the chamber opposite to the chamber door.

In order to obtain a low background noise the test section of the silent wind tunnel is housed inside the anechoic chamber. To keep this low noise level during the aeroacoustic experiments, the wind tunnel was designed such that it does not introduce additional noise (silent wind tunnel). To achieve such an objective, the fan of the wind tunnel was housed outside of the chamber, in the empty space above the ceiling of the anechoic chamber.

The main issue to be addressed in the wind tunnel design and construction was the identification of a flow entry within the anechoic chamber without massive, expensive and destructive actions on the structure of the room. As shown in Fig. 2, the flow entry was decided to be the already existing aperture previously used for ventilation purposes. Since this hole is placed on the opposite top corner of the room entrance, the layout of the room suggested the possibility of using the open door as air outlet during the aeroacoustic experiments. Fig. 3 shows the configuration of the silent wind tunnel.

4 Aerodynamic design

The design goal of the wind tunnel is to perform aeroacoustic measurements at low Mach numbers. For this purpose, the target maximum flow velocity in the test section was set to 20 m/s.

According to the geometrical dimensions of the anechoic room, we found that a suitable configuration is to have a square nozzle of 20 cm edge with a contraction ratio of 6.25. The settling chamber is then a square cross section chamber with 50 cm edge. This nozzle design leads to a volume flow rate in the test section of 2900 m^3/h (at 20 m/s). With the 20 m/s of airflow speed and nozzle dimensions of 400 cm^2, is possible to guarantee the Strouhal similarity for a wide range of aeroacoustic applications of technical interest.

The design value of the volume flow rate, together with the overall pressure drop of the wind tunnel, governs the aerodynamic choice of the driving fan [3]. The pressure drop Δp was computed as the summation of the individual pressure losses estimated for each component of the wind tunnel.

After comparing our design requirements with the data given by different fan manufacturers, the best solutions in terms of pressure increase and noise emission (Table 1) with the Helios GigaBox 560 4/4. It consists of a centrifugal fan driven by a three-phase motor (400 V, 50 Hz) which absorbs a maximum power of 2.5 kW. A frequency regulator was adopted to vary the fan speed.

5 Acoustic design

An essential requirement of an open jet wind tunnel for aeroacoustic measurements is that the background noise level should be significantly smaller (at least 10 dB) compared to a reference test noise that could possibly be investigated in the test chamber [1], for instance the jet noise. The acoustic design of the wind tunnel was conducted according to the technique proposed by Sarradj et al. [11]. Considering the fan as the main source of acoustic disturbances, the acoustic calculation aimed at predicting the background noise induced by it inside the test section all through the wind tunnel conduits [11, 9]. The background noise level was then compared to the reference jet noise.

In general all the fan contributions to the background noise have to be considered in the acoustic design of a silent wind tunnel: upstream, downstream and casing radiation noises.

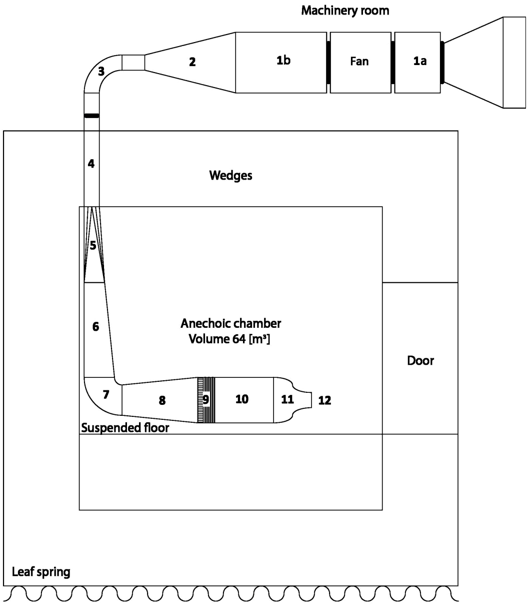

Figure 3: Configuration of the silent wind tunnel housed in the *hepia* anechoic chamber. The elements composing the wind tunnel are: a centrifugal fan, two cylindrical mufflers (1a - 1b); a convergent muffler (2); an elbow (3); a straight unlined duct (4); a round-to-square diffuser (5); a square diffuser (6); a lined absorbing elbow (7); a square diffuser (8); a section with honeycomb and screens (9); a settling chamber (10); and a convergent (11). The test section of the wind tunnel is the open-jet discharge (12).

Especially, in a closed loop wind tunnel, both upstream and downstream sections would need to be designed to damp the noise produced by the fan in both directions. Nevertheless, in our specific case there is no return circuit from the test chamber to the fan. The fan and its aspiration port are placed in the machinery room right above the anechoic chamber avoiding a direct contact with the test section. For these reasons, their contribution to the background noise was neglected and only the downstream fan noise reaching the test section by the nozzle was considered. Furthermore, the transmission of structural vibrations from the fan casing to the test chamber is prevented by the use of soft connections with the adjacent ducts and by

Sound Power Level	**125**	**250**	**500**	**1k**	**2k**	**4k**	**8k**	
$L_{W,Fan}$ (@ max speed)	78.1	82.6	78.2	75	72.8	69	62.1	Given by the manufacturer

Table 1: Fan SWL in octave bands

Figure 4: Wind tunnel setup in the machinery room above the anechoic chamber.

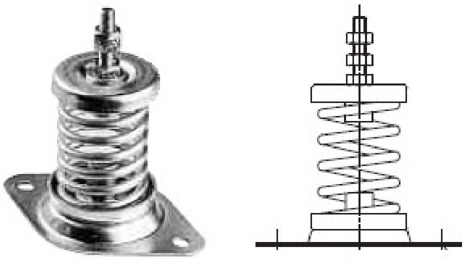

Figure 5: Fan casing silent block - Helios catalog.

silent block connections on its base.

In order to damp the noise propagated downstream from the fan (Fig. 3), a cylindrical muffler (Fig. 3-1b) and a convergent muffler (Fig. 3-2) are used. Similar silencer arrangements have been already introduced in many acoustic wind tunnel facilities as describerd by Mueller [8]. In particular, the convergent downstream of the fan (Fig. 3-2) is necessary to reduce the duct section to size of the aperture used for the ventilation of the room (Fig. 2). The vertical conduit (Fig. 3-3,4,5,6) presents: a narrow corner, high flow velocities and a diffuser. These elements introduce new flow-generated noise that needs to be damped. On this purpose, the last components of the wind tunnel before the open jet were acoustically treated. The elbow downstream of the diffuser (Fig. 3-7) is lined both on the walls and on its turning vanes; In a similar manner, the settling chamber walls (Fig. 3-10) are acoustically lined.

6 Mechanical design

As shown in Fig. 4, all the elements installed in the machinery room were hung on the room ceiling (room's top wall) in order to preserve the modal separation of the anechoic camber from the rest of the bulding. Moreover, as better explained in the following sections, the fan was assembled in the structure carefully avoiding rigid connections in order to avoid solid noise transmission.

When possible, commercial sound absorbers have been used, but when particular shapes were necessary the acoustic damping elements were manufactured at the *hepia* workshop. In all these cases a dynaphon absorbing material panel was used, which was held in place by a perforated stainless steel plate. The perforation pattern of this plate was chosen according to Mueller [7] and Schultz [12] in order to guarantee a reasonable transparency index to the acoustical radiation.

In most of the sections of the wind tunnel, static pressure probes were installed for troubleshooting purposes. This enables the investigation of the experimental head losses all along the tunnel.

As shown in the right picture of Fig. 2, at present only the bare wind tunnel construction materials were left in the anechoic chamber without absorbing coating. In the future work, all the rigid sections exposed to the test room will be covered to limit the acoustic reflections.

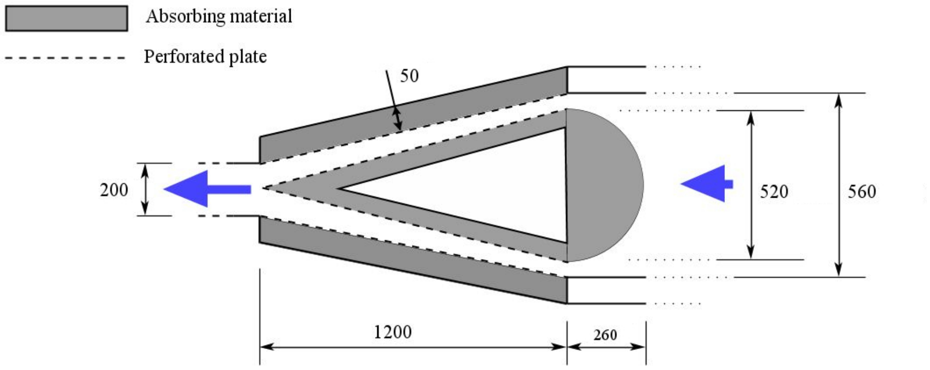

Figure 6: Convergent muffler's schematic drawing, units are in mm.

6.1 The Fan and the cylindrical silencers

In order to avoid the propagation of vibrational solicitations from the motor, the centrifugal fan (Helios GigaBox 560 4/4) and the cylindrical silencers (Helios RSD series, elements 1a and 1b in Fig. 3) were assembled together by means of flexible junctions, represented in Fig. 3 by thick black lines. Moreover, for the same purpose, the fan casing was connected to the hanging frame by means of spring silent blocks (Fig. 5).

6.2 The convergent muffler

Downstream of the commercial muffler (Fig. 3-1b), a convergent section (Fig. 3-2) had to be installed to fit the dimension of the old ventilation duct and to enter the anechoic chamber. To increase the acoustical damping of the wind tunnel, the external wall of this contraction cone was lined with a 5 cm thick layer of absorbing material (Dynaphon B810 50). In order to further increase the acoustic damping of the section and to avoid the direct radiation of the fan noise past the convergent, an absorbing cone was manufactured and was installed in the convergent as shown in Fig. 6.

6.3 The first elbow

Downstream the convergent silencer, the flow has to bend downwards, in the direction of the anechoic chamber. To limit the flow losses due to the reduced duct diameter and to the small curvature radius, three panels were installed inside the elboe as flow separators. Downstream of the first elbow, a straight duct section enters inside the anechoic chamber, where a divergent section slows down the flow and changes the cross section shape from circular to square.

6.4 The second elbow

The second elbow, necessary to redirect the flow towards the exit door, has a square cross section bending with concentric radii. To reduce the head losses and generate an uniform flow downstream, it has two flow separators [3] shaped as airfoils and installed with respect to the elbow rotation center at the distances imposed by Eq. (1) [3]:

$$r_i = 1.26 r_{i-1} + 0.07 b_0 \tag{1}$$

where b_0=400 mm is the size of the square section.

The second elbow is an acoustically absorbing element. As shown in Fig. 7, both the external casing and the turning vanes were lined with absorbing material (Dynaphon B810 50).

In order to insure the stiffness of the absorbing flow separators, the leading and trailing edges were manufactured in wood. Moreover, the foils' upper and lower surfaces, riveted to the wooden elements, were made in bent perforated stainless steel, holding together a shaped Dynaphon panel.

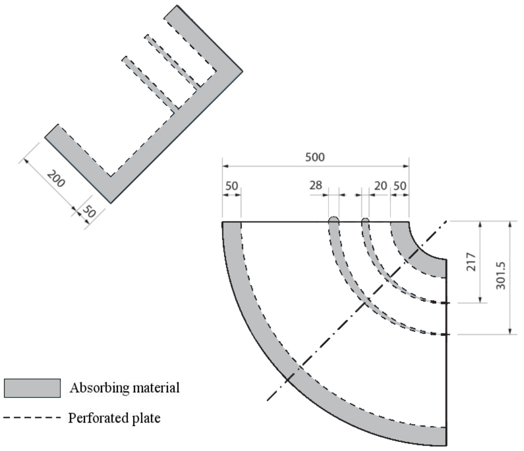

Figure 7: Second elbow section's schematic drawing, units are in mm.

6.5 The settling chamber

Downstream of the second elbow lays the last diverging element, bringing the dimension of the duct to the size of the settling chamber, which is 1 m long with a 500 mm side square cross section.

The settling chamber walls were covered with 40 mm thick Dynaphon B810 foam, using the same technique as for the other wind tunnel's absorbing elements. Inside the settling chamber, a honeycomb and several screens were installed to insure the flow quality in the test section [10, 4]. The screens were installed on wooden frames housed between the absorbing elements. As shown in Fig. 8, the settling chamber can be easily opened and the wooden frames are easy to change. This modular design was chosen to simplify the aerodynamic tuning of the facility once the construction was finished.

The mainframes of the last divergent and of the settling chamber (elements 8 and 10 in Fig. 3) were manufactured in wood to limit the vibrations induced by the flow instabilities. Moreover, the use of wood has simplified the subsequent modification operations necessary for the commissioning of the facility. Nevertheless, the use of wood in a removable facility is to be done with caution, since the wood can't withstand several mounting and unmounting operations. For this reason, stainless steel flanges were installed at the extremities of the wooden elements and rubber joints were used to insure the air-tightness.

Figure 8: Settling chamber assembly.

6.6 The nozzle

Since the settling chamber and the test section were designed to have respectively the sides of 500 mm and 200 mm, the contraction ratio of the wind tunnel nozzle was fixed to 6.25.

The profile of the contraction cone was chosen according to Morel and Su [5, 6, 13], aiming at minimizing its length without generating flow separations and turbulence in the test section.

The side walls of the nozzle were built in 7 mm thick aeronautic flexible plywood, that could be bent in one direction. Moreover (Fig. 9), the nozzle's surfaces were designed to be held in place by a wooden external frame and by a steel flange connecting it to the previous element.

A second metal flange was installed at the nozzle exit. On both (inlet and outlet) metal structures, rings of static pressure probes were mounted. These pressure rings were correlated to pitot tube measurements and are currently used to measure the wind speed in the test sec-

Figure 9: Wind tunnel nozzle.

tion.

7 Conclusions

After the design of the wind tunnel, the aeroacoustic facility was built. Today the authors are working on the stabilisation of the flow in the vertical diffuser. Moreover, the wind tunnel's surface exposed to the anechoic chamber still needs to be lined in absorbing foam.

A preliminary characterisation of the wind tunnel was conducted after its construction, but a complete investigation will be carried out in the next future.

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