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CHARACTERIZATION OF ISAE-SUPAERO AEROACOUSTIC WIND TUNNEL

H. Parisot-Dupuis **Y. Bury** **P. Barricau** **B. Mellot**
ISAE-SUPAERO, Université de Toulouse, Toulouse, France

ABSTRACT

Within the framework of aeroacoustic studies, ISAE-SUPAERO has invested in the conception of a new wind tunnel. This facility consists in a closed loop, open-jet anechoic wind tunnel designed for low subsonic aerodynamic noise studies. The air jet exhausts from a square section, 7.1 contraction nozzle ($D = 1.8\ m$) into an anechoic room ($L = H \sim 7\ m$, $W \sim 8\ m$) whose cutoff frequency is $200\ Hz$. It is then collected thanks to a 4-large-chevron-based collector at the end of the room. The free-stream velocity ranges between $10\ m/s$ and $80\ m/s$, giving access to Mach numbers up to 0.23. Both aerodynamic and acoustic performances were investigated in order to determine the operational characteristics. Flow uniformity and longitudinal static pressure gradient were measured to assess the specifications. It is found that the airflow quality allows to perform measurements on mockups positionned up to $2D$ from the nozzle at maximal flow speed. Acoustic measurements reveal that the acoustic treatments provide a background noise level below $77.5\ dB(A)$ in the $200 - 20000\ Hz$ frequency range for the highest free-stream velocity. This wind tunnel will allow the laboratory to carry out experimental studies dedicated to the noise generated by airframe elements.

Keywords: *aeroacoustics, wind tunnel, anechoic room*

1. INTRODUCTION

The sound generation from bodies in interaction with an airflow is a concern for many applications, especially for noise pollution due to transportation in cities [1]. In order to reduce the noise coming from these equipments, it is necessary to understand the mechanisms responsible for their generation. Such problematics can be tackled by means of wind tunnel testing. In this case the facility should produce a sufficiently low background noise level with respect to the source of interest and have a test section that limits sound wave reflections. This can be done by using a wind tunnel initially designed for aerodynamic testing and upgraded for aeroacoustic measurements by adding acoustic treatments in the circuit and the test section [2, 3], or by using a wind tunnel especially designed for aeracoustic testing [4–9]. The latter option was chosen at ISAE-SUPAERO, which has invested in the conception of a new aeroacoustic wind tunnel.

This paper presents this new facility. First, the main technical caracteristics of the wind tunnel are depicted. Then experimental methods used to investigate the wind tunnel performances are presented. Finally, a first serie of results of aerodynamic and acoustic characterization are reported and discussed.

2. WIND TUNNEL PRESENTATION

The ISAE-SUPAERO aeroacoustic wind tunnel (SAA) is a closed-circuit, open-jet subsonic wind tunnel whose general layout is illustrated in Figure 1.

The circuit presents four corners equipped with shaped turning vanes to prevent airflow separation. The facility is powered by a $920\ kW$ asynchronous variable speed motor driving a $3.35\,m$ diameter axial fan up to 744 revolutions per minute, and located between corners two and three. A heat exchanger is on the third corner, downstream of the fan and motor, to ensure temperature stabilization. After the heat exchanger, the flow is guided into a $4.8\,m$ settling chamber equipped with a honeycomb and a turbulence screen to ensure the flow uniformity and reduce

**Corresponding author*: *helene.parisot-dupuis@isae-supaero.fr.*

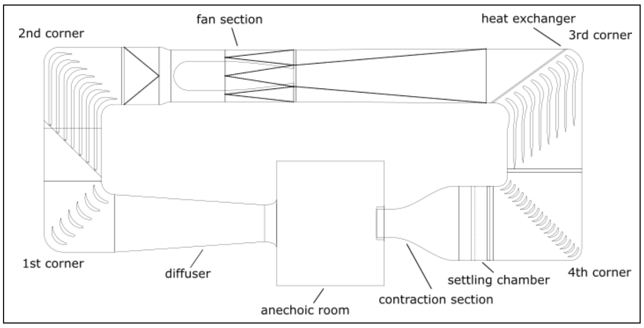

Figure 1. Overview of ISAE-SUPAERO aeroacoustic wind tunnel (SAA).

the overall turbulence. The airflow exits then from this chamber through a 7.1 contraction nozzle, which accelerates the airflow up to a maximum speed of 80 m/s (without blocage) through a square cross section of 1.8 m side. Downstream of the test section, the airflow is collected by a 4-large-chevron-based collector and guided back to the fan section through a 10.4 m-long diffuser. The pressure inside the test section is balanced with the outside static pressure through small dedicated apertures in the walls.

The circuit is equiped with acoustic treatments on walls and ceiling, as well as inside the turning vanes and the collector to attenuate fan, motor and airflow noise propagation towards the test section. The fan is also structurally decoupled from the circuit to limit vibration transmission. The open test section is in an anechoic room of approximately $7 * 7 * 8\, m^3$ (L*H*W) wedge-tip to wedge-tip. Removable wedges are used on the floor to create a fully anechoic environment.

3. MEASUREMENT METHODS

3.1 Aerodynamics

2D2C particle image velocimetry (PIV) technique is used to estimate airflow characteristics in a non-intrusive way. Illumination is provided by a Litron Bernoulli Nd:YAG double-pulse laser, which provides output energies of up to 200 mJ per pulse at $\lambda = 532\ nm$. The camera is a FlowSense EO16M model ($4872 * 3248$ pixels) from Dantec fitted with a ZEISS objective ($F = 85\ mm$ / $NA = 1.4$). A Martin fog machine located at the end of the diffuser is used to seed the airflow. The delay between the 2 laser pulses used for the cross-correlation is fixed to 20 μs for the measurement of the particle displacement, and an acquisition of 500 velocity fields sampled at 2 Hz is used for the calculation of statistical moments. A dedicated calibration target was designed to carry out these PIV measurements characterized by large fields of view ($\sim 1\ m$ of side). This allowed to measure the velocity components in longitudinal planes centered at distances between 1 to 4 m from the nozzle exit. Data are then post-processed to estimate the velocities using an adaptive PIV algorithm.

Steady measurements with a pitot probe type L (model NPL from Kimo) associated to a PD-41X Keller pressure transmitter are also performed in the jet.

3.2 Acoustics

Acoustic measurements using a $1/4\ in.$ GRAS 40PH microphone are performed to assess the background noise level. Acoustic data are acquired at a sampling frequency of 51.2 kHz during 16 s and third octave band spectra are obtained from time signals using ANSI S.1.11 / IEC 61260 octave filtering.

Anechoïcity is also assessed using the procedure described by standard ISO 3745. A pink noise is generated by a monopolar Q-MHF source from Siemens located at the center of the test section, and measurements are performed on several diagonals at distances between 0.5 and 3.5 m from the source.

4. WIND TUNNEL CHARACTERIZATION

Fisrt results of the aerodynamic and acoustic characterization are hereafter presented using a cartesian, coordinate reference frame with the origin at the center of the nozzle exit. The x-axis is aligned with the jet axis, y-axis and z-axis are horizontal pointing towards the right side of the pilot, and vertical pointing upwards respectively.

4.1 Aerodynamics

This section discusses the quantification of the airflow quality. The airflow uniformity is assessed at the maximal speed $U_0 = 80\ m/s$ for different distances from the nozzle: $x = [1; 2; 3; 4]\ m$. Figure 2 presents the mean value U of the flow velocity along x measured on the lower part of the jet (i.e. negative z). Results are normalized with respect to U_0 and the nozzle size $D = 1.8\ m$.

The velocity profiles show a top-hat distribution near the nozzle exit which evolves to a Gaussian shape when going downstream, revealing the development of the jet shear layer. At a distance of $x/D = 2.22$, the extent of the free jet with a constant velocity covers 70% of its original extent. Hence, it can be noticed that the jet potential core has a length that exceeds three nozzle diameters.

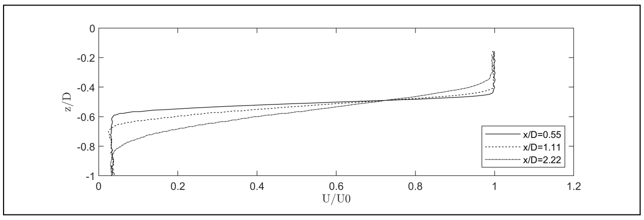

Figure 2. Evolution along the jet axis of the normalized mean velocity U at 80 m/s.

The longitudinal static pressure gradient was also measured along the jet axis at same distances from the nozzle. Normalized results are shown in Figure 3. The static pressure peak-to-peak variation is less than ± 0.005 in C_p until $x/D = 2.22$, which confirms the possibility to perform aeroacoustic tests with a mockup located up to $x/D = 2$.

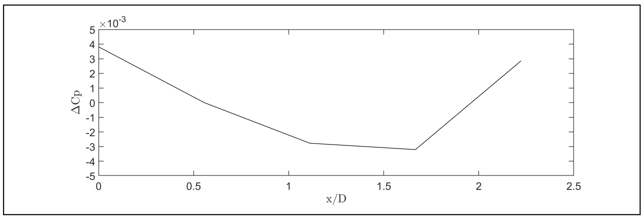

Figure 3. Evolution along the jet axis of the static pressure gradient ΔCp at 80 m/s.

4.2 Acoustics

First, the anechoicity of the test section is measured following standard ISO 3745, by assessing the monopole radiation decrease, 6 dB per doubling of distance in free field, on several diagonals starting from the center of the test section. An example of sound pressure level (SPL) deviations obtained on one diagonal between measured third octave band spectra and theoretical ones is presented in Figure 4 for distances 0.5 to 3.5 m every 0.1 m from the anechoic room center (dashed lines correspond to the limits given by ISO 3745). Results appear to be within the range of the standard in the $200 - 20000$ Hz frequency range, which ensures acoustic measurements in free field in this range.

The background noise SPL measured 3 m from the nozzle exit and 3 m in sideline (i.e. positive y) without airflow and at 80 m/s are also presented in Figure 5. These results are analyzed on third octave bands for which the anechoicity is verified, with the resulting overall sound pressure levels (OASPL) on the right. This leads to an OASPL below $81.5\,dB$ / $77.5\,dB(A)$ at the maximal speed in this frequency range. No tones are clearly visible on this spectrum and the SPL decreases mononotically with the frequency as in jet noise theory, which indicates that the acoustic treatment of the circuit seems sufficient to prevent fan, motor and airflow noise propagation in the test section.

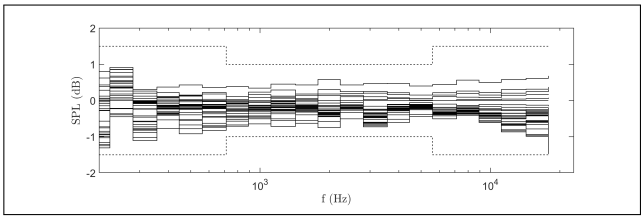

Figure 4. Third octave band SPL deviations measured at distances between $0.5\,m$ and $3.5\,m$ from the anechoic room center on a diagonal towards the collector. ISO 3745 limits are indicated in dashed lines.

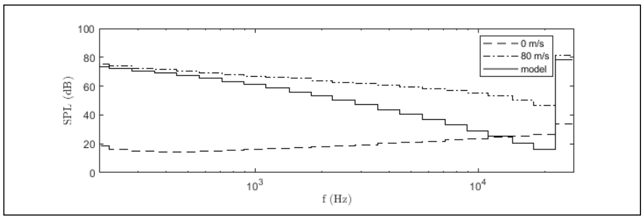

Figure 5. Third octave band background noise SPL measured 3 m from the nozzle exit and 3 m in sideline at 0 and 80 m/s. Predicted SPL at 80 m/s are indicated in solid line.

A comparison with a simplification of a noise semi-empirical model for low jet Mach number and temperature [10] is also presented:

$$SPL = 129 + 10log_{10}(\frac{S_0}{r^2}) + 75log_{10}(M) - 8.4(log_{10}(\frac{f}{f_p}))^2 \quad (1)$$

where S_0 is the nozzle exit surface area, r the distance to the jet axis at an angle of 90°, M the jet Mach number and $f_p = 0.9 * U_0/D$ the peak frequency. While the model prediction agrees with the measured maximum levels at low frequencies, it decreases faster than the measured levels in the high frequency range. This might be due to the fact that empirical coefficients used in this model were initially derived for jets with higher Mach numbers. It can also be noticed that predicted levels are slightly lower than the background noise without airflow on the last third octave bands. The wind tunnel seems thus to present a sufficiently good anechoicity and low background noise in the test section to confidently perform near- and far-field acoustic investigations.

5. CONCLUSIONS

A first characterization of the new ISAE-SUPAERO aeroacoustic wind tunnel (SAA) was performed. This facility is a closed loop, open-jet subsonic wind tunnel associated with an anechoic room.

The jet, produced by a square nozzle of side $D = 1.8\ m$ and 7.1 contraction rate, can reach velocities ranging from 10 to $80 m/s$ before being collected by a 4-large-chevron-based collector. Airflow uniformity was assessed at the center of the jet for distances between 1 to $4\,m$ from the nozzle exit. These results, as well as the evolution of the longitudinal static pressure gradient, show the possibility to perform measurements with a mockup located at distances from the nozzle exit up to $2D$.

The anechoic room of approximately $7 * 7 * 8\ m^3$ (L*H*W) is acoustically treated with wedges, which leads to a cutoff frequency of 200 Hz following standard ISO 3745. Acoustic treatments are also implemented in the major part of the circuit, allowing to reduce noise coming from it and to obtain a background noise level below $77.5\ dB(A)$ in the $200 - 20000\ Hz$ frequency range for the highest free-stream velocity of $80\ m/s$.

An additional test campaign is planned to complete the wind tunnel characterization. This facility will then allow the laboratory to study the noise emitted by aircraft equipements up to 0.23 Mach numbers, corresponding for instance to landing configurations.

6. ACKNOWLEDGMENTS

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