DEVELOPMENT AND TESTING OF AN AEROACOUSTIC WIND TUNNEL TEST SECTION

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1 Introduction

The medium-speed wind tunnel at Carleton University was acoustically treated to create an environment for acoustical research. In order to develop aeroacoustic studies, many wind-tunnels with capacities to execute aeroacoustic tests have been designed around the world [1-3] or adapted from a pure aerodynamic wind tunnel [4, 5]. To develop the present investigation, the Carleton University aerodynamic wind tunnel has been upgraded in order to carry out this research.

2 Wind tunnel characterization

The experiments were conducted in the medium-speed, sub-sonic, closed-loop wind tunnel at Carleton University, as shown in Figure 1. The airflow is powered by a 37.3 kW (50 HP) variable-speed DC motor driving a 1.2 m axial propeller at speeds as high as 40 m/s. A variable frequency drive (VFD) modulates the rotational frequency of the fan at a resolution of 1Hz. A series of turbulence grids precede a 9:1 contraction, which reduces the turbulence intensity levels in the centre of the test section to less than 0.27%, as measured for speeds up to 15 m/s.

2.1 A new aeroacoustic test section

A new test section (shown in Figure 1) along with the surrounding anechoic chambers were designed and manufactured in order to be used for aeroacoustics testing. This test section is a 0.78 m x 0.51 m rectangular section, 1.83 m long. The upper and lower walls of the test section are each composed of two aluminum sheet panels and contain hardware (circle aluminum material) for the vertical mounting of two dimensional airfoil midway between the acoustic windows (i.e. test section side walls), and 0.45 m from the upstream end of the test section. The two sides of the walls of the test section are made of stretched, thin-weave cloth covering a streamwise length of 1.83 m, which provides a smooth flow surface and also a significant reduction in lift interference effects when compared to that of an open-jet test section. Cloth window allows sound to pass through the walls into the anechoic chambers with very little attenuation.

3 Anechoic system

3.1 Physical layout

The wind tunnel has an anechoic system that consists, primarily, of an aeroacoustic test section and two anechoic chambers (shown in Figure 1). The two anechoic chambers

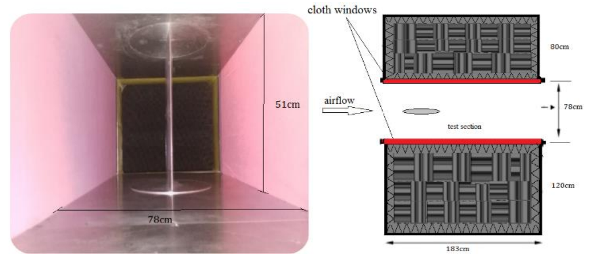

Figure 1. Left: photograph taken from downstream showing the test section interior. Right: cross section through the aeroacoustic test section and anechoic as seen from above.

are positioned on either side of the aeroacoustic test section to capture the sound emitted through the acoustic windows and reduce sound reflections inside the section.
The chambers are joined together with bolts and clamps to maintain a pressure seal. Both chambers have the same streamwise length of 1.83 m and different depths of 0.8 m right-side, and 1.2 m left-side. The chambers are lined with 0.015 m carpet bed and, 0.05 m acoustic wedged foam designed to reduce acoustic reflections.

The regions around each of the acoustic windows are covered with a carpet-bed and acoustic foam transitions to cover up all of the hard surfaces within the chamber. The chambers are each equipped with a door for access to the inside of the chamber, and for installation of data acquisition equipment. The entire system is removable so that the wind tunnel can be switched from a hard-walled configuration to an anechoic, and back again.

4 NACA0012 airfoil model

A NACA 0012 airfoil model was used as a benchmark test. The chord of the airfoil is 0.3 m, and the span is 0.51 m. The 2D airfoil is manufactured as two halves, each one composed of six pieces with eight screws. Eight holes were drilled on each side of the chord length of the airfoil, so this can be fixed on the circle rotating mechanism. The trailing edge is 0.08 m wide, and the leading edge is 0.08 m.

5 Results and discussion

5.1 Background noise measurements

The background noise of the wind tunnel was measured in the anechoic chamber with a single calibrated B&K microphone. Figure 2 shows empty test-section background sound pressure levels (SPL) in the starboard-side anechoic chamber as a function of flow speed, 0 m/s to 24 m/s. Noise levels in the port-side chamber are nearly identical. These measurements were made 1.4 m from the test-section centre. The highest spectral levels can be seen at low frequencies (100-500 Hz). Background noise levels for frequencies less than 500 Hz are mostly tones generated by the wind tunnel fan. Frequencies

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above 500 Hz are believed to be due to a combination of noise sources including the fan, turning vanes, and scrubbing noise from flow surfaces in and around the test section. The peaks showed at 3 kHz, 4.5 kHz and 6 kHz are mostly associated with motor tones. To estimate the acoustic performance, the A-Weighted overall sound pressure level, OASPL, is compared to other acoustic facilities around the world.

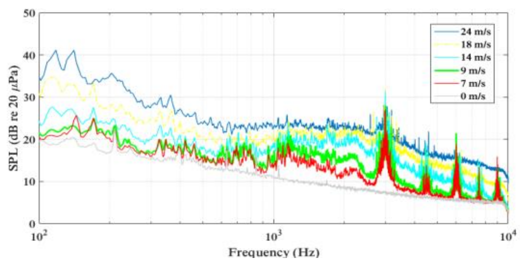

Figure 2. SPL in the starboard-side anechoic chamber as a function of flow speed in the empty test section.

Since the nozzle dimensions and microphone positions are different, the measured results must be transformed before comparing with each other. The equation is [3]:

$$OASPL_{corrected} = OASPL_{measured} - 10 \operatorname{Log}_{10} (S / R^2) \qquad (1)$$

where R and S are the distance from the microphone to the wind tunnel centre-line and nozzle exit area, respectively.

The Carleton University wind tunnel background noise is scaled using Equation (1), and results are shown in Figure 3. Background noise of other acoustic facilities with data obtained from the literature [1, 3, 6] are also plotted in Figure 3 for comparison. Results indicate that background noise of the Carleton University wind tunnel is comparable.

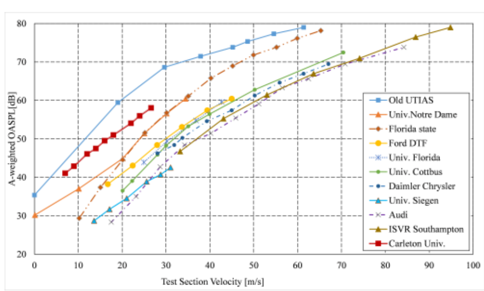

Figure 3. A-weight SPL for Carleton University wind tunnel compared with other aeroacoustic facilities around the world.

5.2 NACA0012 airfoil TE noise measurements

NACA0012 airfoil with straight and sawtooth TE was submerged within the potential core of the jet to assess TE self-noise in relation to wind tunnel background noise. The airfoil was held at zero angles of attack by side plates extended from the nozzle sidewalls. The radiated noise was measured at 1.4 m from the centre of the TE in the starboard-side, which corresponds to a 90^0 of polar angle. At first, the background noise of the wind tunnel was measured under free stream velocity of 14 m/s and 24 m/s. The airfoil with straight TE, as a reference, and the same airfoil with sawtooth TE were then attached to the sidewalls, and the same free stream velocities tests were conducted. Results for the TE self-noise spectra for these cases are plotted in Figure 4. It is shown that the serration geometry is effective in reducing TE noise. The TE self-noise measurement is seen to be more than 10 dB above the background wind tunnel noise, which guarantees the validity of the results.

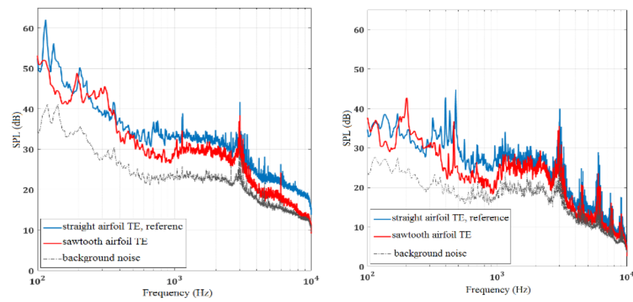

Figure 4. Measured SPL spectra for NACA0012 airfoil at free-stream velocities 14 m/s (left) and 24 m/s (right).

6 Conclusion

A small-scale aeroacoustic wind tunnel test section was built at Carleton University. The layout of the wind tunnel has been described in this paper. Aeroacoustic performance is measured and evaluated. Results show that the background noise can be comparable with other aeroacoustic wind tunnels. A simplified airfoil is tested as a benchmark test. Results show that the serration geometry is effective in reducing TE noise and that noise radiated from the TE is at least 10 dB higher than the background noise, satisfying the requirements for aeroacoustic measurements.

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