Acoustics Of Aero-Acoustic Wind Tunnels – State Of The Art

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1 Introduction

Wind tunnels continue to be used extensively for the development of aerospace vehicles and ground vehicles. An area seeing continued growth is in aero-acoustic testing. For ground vehicles, primarily cars and SUVs, the emphasis is on interior noise sources, though the exterior background sound field must be sufficiently low. The main focus of this paper is a general description of the aero-acoustic aspects of wind tunnels. The resulting noise characteristics and progression through time of the achieved background noise level with each new wind tunnel are then summarized.

2 Wind tunnels

A schematic detail of open-jet closed loop configuration of a wind tunnel for aero-acoustic purposes is shown in Figure 1.

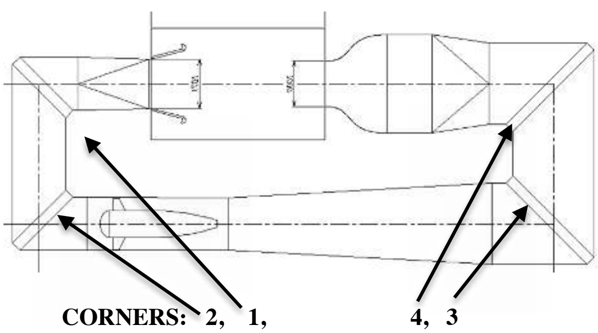

Figure 1: Configuration of an open-jet, closed loop tunnel.

In a closed loop tunnel, there are four sections of the circuit, starting with the test section, two corners, fan section and two more corners with the required diffusion and contraction to provide a smooth flow within the test section. In addition, a heat exchanger with arrays of tubes (finned or not) is usually installed in the settling chamber upstream of the nozzle contraction to remove the heat generated by the fan.

3 Noise sources

The main noise source in any wind tunnel is the main fan, which is usually an axial fan, with strong low frequency components. The flow speeds at Corners 1 and 2 can be high and mid-to-high frequency noise would be generated by the turning vanes.

Control methods to reduce the noise levels are: a) silencers upstream and downstream of the fan; b) lining the turning vanes with absorbent materials; c) lining the duct surfaces with noise reduction materials; and d) lining the open jet test section walls with acoustic wedges or thick absorbent panels [1 - 3]. The acoustic treatment attenuate the fan noise sufficiently such that local noise sources in the test section become significant. Noise levels generated by various sources are shown in Figure 2 [4].

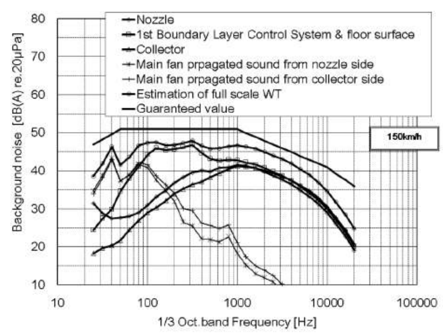

Figure 2: Predicted noise levels of Toyota's 1/10th model tunnel [4].

Strong Aeolian tones will be generated at set frequencies by the heat exchanger tubular array. Depending on the location of the heat exchanger, the tones can be amplified if they coincide with the standing wave resonant frequencies of the wind tunnel section. The resulting sound levels can be as high as 140 dB at the Aeolian tone coinciding with the standing wave resonance. The impact of shedding vortices and settling chamber resonances are highlighted in Figure 3. Different measures such as flow blocking at resonance anti-node locations and acoustic treatment are required to eliminate these tones.

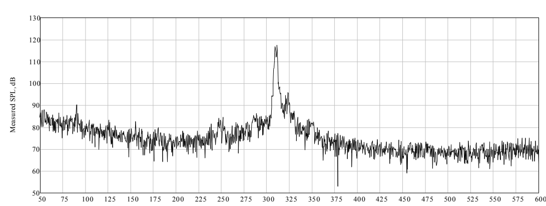

Figure 3: Measured sound spectrum adjacent to a heat exchanger during resonance.

Another resonance phenomenon that can impact the test section noise levels is from coupling of the shear-layer fluctuations with resonance modes in the circuit, primarily full-circuit organ pipe modes and the nozzle collector

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feedback mechanism (vortices shed from the nozzle impacting the rear of the test section and feeding back to the nozzle). These "organ pipe" modes result in very low-frequency resonances of the order of several Hz for full-scale automotive wind tunnels. Even though inaudible, the circuit resonance can disturb the flow substantially. Methods developed to minimize these resonances include the use of nozzle exit vortex generators (to alter the frequency of the shed vortices), inducing entrained air from outside to flow through the test section (to lessen the shear layer strength), active noise control, and the use of passive Helmholtz resonators [3]. A sample circuit resonance event, at 2.3 Hz, and attenuation using a Helmholtz resonator are shown in Figure 4 below.

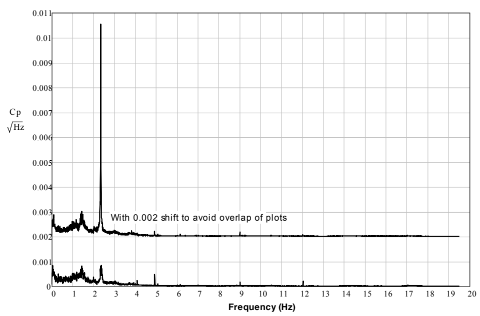

Figure 4: Circuit resonance (upper line) and with resonator (lower line)

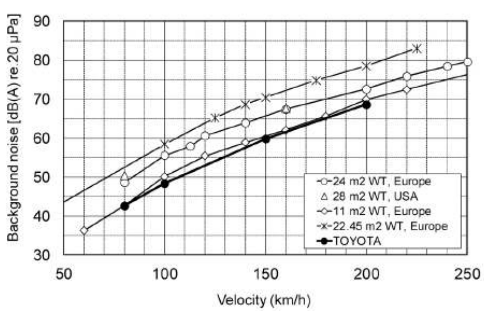

Figure 5: Test section OASPLs of a set of aero-acoustic tunnels [4].

4 Acoustical requirements

The increasing demand for acoustic testing of vehicles has led to a continuing reduction of the background noise in the test section as can be seen in the Figures 5 and 6 [data from references 4 thru' 13]. The more recent wind tunnels, and specifications for new ones, represent diminishing returns for noise suppression within the wind tunnel. The primary noise sources remaining are from the boundary layer, especially the boundary layer reduction system, and the flow at the collector (at the rear of the test section). There are indications that the new automotive acoustic wind tunnels are quiet enough to meet the demands for acoustic testing, at least at present [6, 12]. Improved noise measurement techniques such as 3D beamforming with simultaneous interior measurements could further diminish the need for additional background noise reductions in the test section.

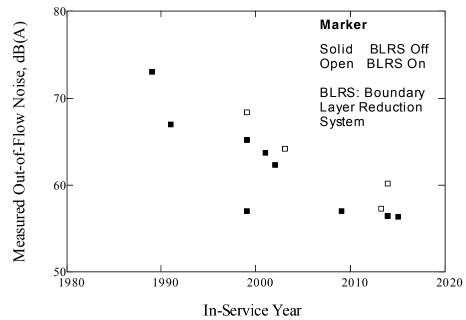

Figure 6: Chronological improvement to out-of-flow OASPLs in automotive aero-acoustic tunnels. Measurement locations not entirely consistent. Wind speed = 140 m/hr

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