UNCOMMON NOISE SIGNATURES IN A WIND TUNNEL

R. Ramakrishnan, M. Rennie and S. Lau
Aiolos Engineering Corporation, 2150 Islington Avenue, Toronto, M9P 3V4

1.0 INTRODUCTION

Wind tunnel testing has become an important part of all aspects of road vehicle design. In addition to the well-known use of wind tunnels for the aerodynamic or aero-acoustic optimization of new vehicle designs, smaller wind tunnels are also used to investigate engine cooling, HVAC, and other aerodynamic integration issues. For these small, "climatic" wind tunnels, test-section acoustic noise levels are not a significant factor in the design of the wind tunnel; however, control room ambient noise levels are very often specified as part of occupational safety considerations. Limits on control room ambient noise levels are typically in the range 60 to 70 dBA over the full wind-speed range of the facility.

As a general rule, acoustic noise in a wind tunnel originates with the fan, and the bulk of the acoustic design effort for a new wind tunnel focuses on reducing the noise of the main fan. However, secondary noise sources many times stronger than the main fan may occur when the wind-tunnel flow excites resonant vibrations of an internal structure within the wind tunnel circuit. These flow-structure interactions can be complex in nature, are often not well understood, and are difficult to predict beforehand. As a result, these types of noise problems do not become apparent until the first wind-on startup of the wind tunnel, and must be rectified during the startup and commissioning phase of the facility. This paper describes an on-site investigation that was undertaken to correct a resonant tone that was eventually traced to the main fan support structure.

2.0 CIRCUIT DESCRIPTION

A schematic of the wind tunnel circuit is shown in Figure 1. The test section, where the test vehicle is located, is shown at the lower right of the figure. The control room is located next to the test section, at the same height as the test vehicle. The wind tunnel is an "overhead return" design, meaning that the return leg, which includes the main fan, is built on top of the test section. The air is guided through the wind tunnel circuit using flat-plate, circular-arc turning vanes located at each of the four corners. A heat exchanger is located in the settling chamber for temperature control. The temperature range of the facility is –40°C to +50°C.

3.0 TUNNEL NOISE LEVELS

The noise levels measured in the control room for three test-section wind speeds are plotted in Figure 2. In addition to these data, the following observations were made:

a) Strong tones were observed from a wind speed of 90 kph up to the facility maximum wind speed of 200 kph.

b) The tone frequency increased with wind speed; however, the frequency was not a linear function of wind speed.

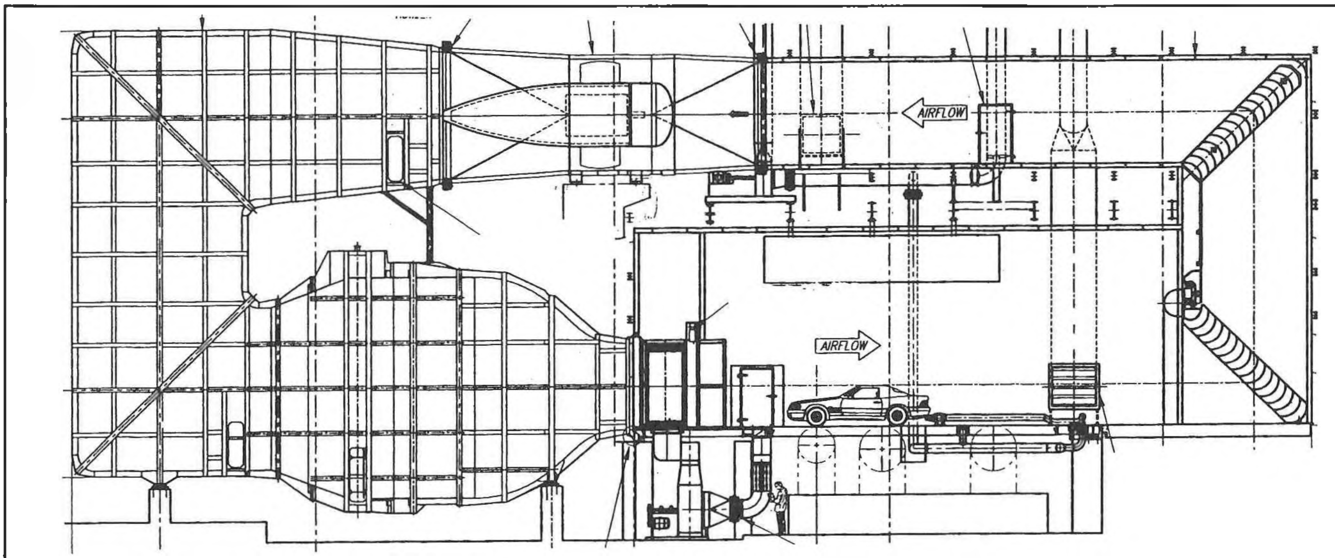


Figure 1. Typical details of a Climatic Wind Tunnel.

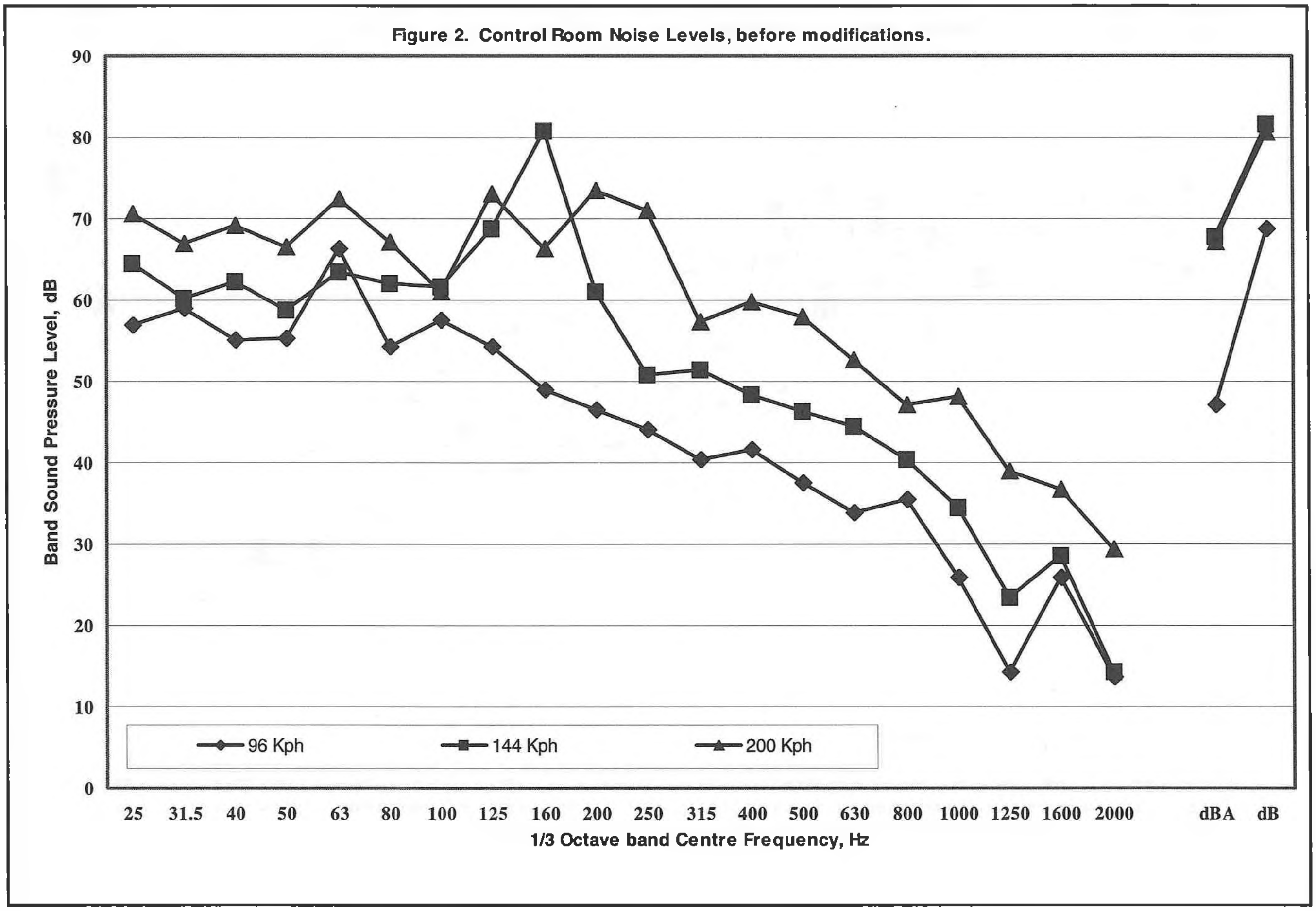


Figure 2. Control Room Noise Levels, before modifications.
Band Sound Pressure Level, dB
0
10
20
30
40
50
60
70
80
90
96 Kph
144 Kph
200 Kph
25
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1000
1250
1600
2000
dBA
dB
1/3 Octave band Centre Frequency, Hz

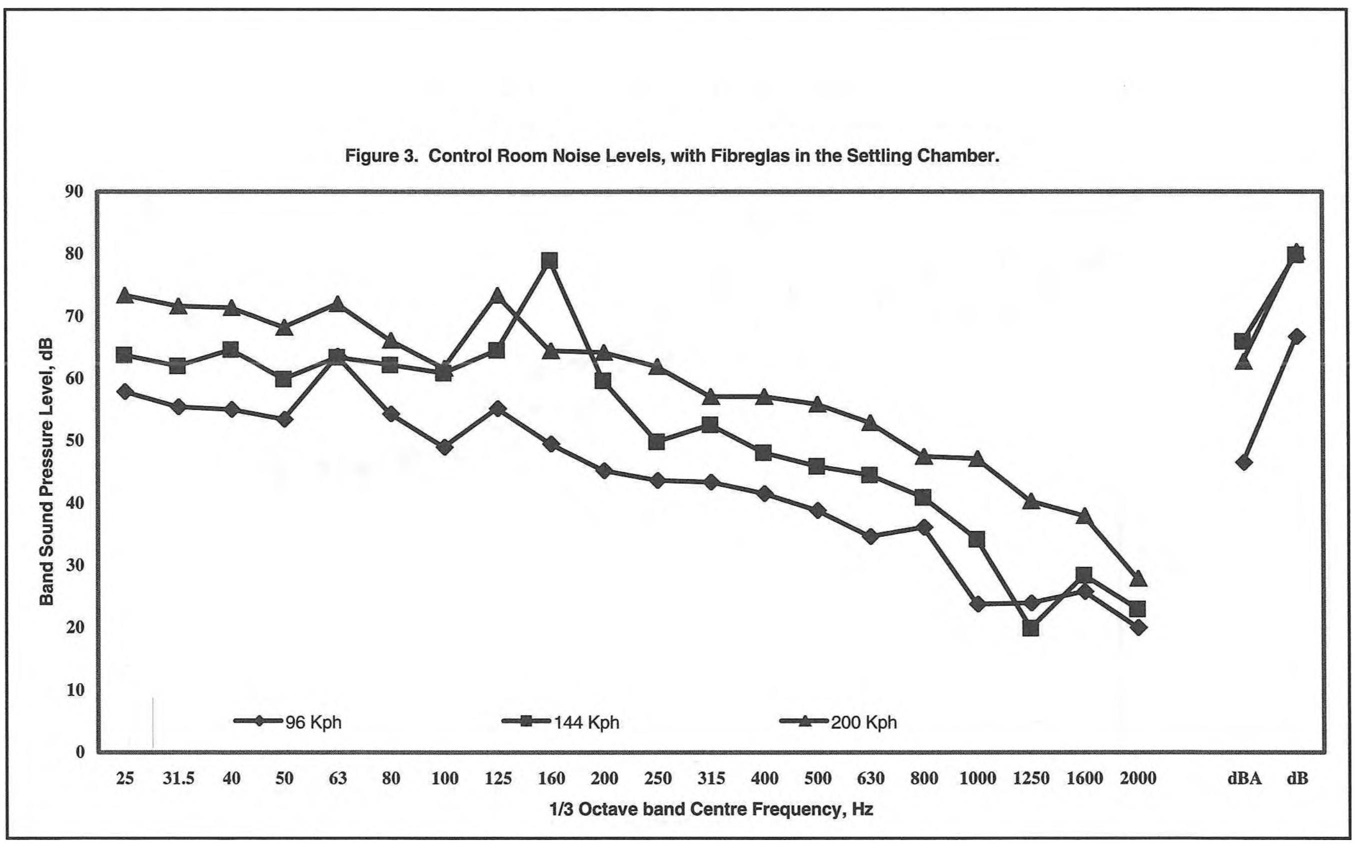


Figure 3. Control Room Noise Levels, with Fibreglas in the Settling Chamber.
Band Sound Pressure Level, dB
0
10
20
30
40
50
60
70
80
90
96 Kph
144 Kph
200 Kph
25
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1000
1250
1600
2000
dBA
dB
1/3 Octave band Centre Frequency, Hz

Figure 4. Control Room Noise Levels with weights on the Support Plate.

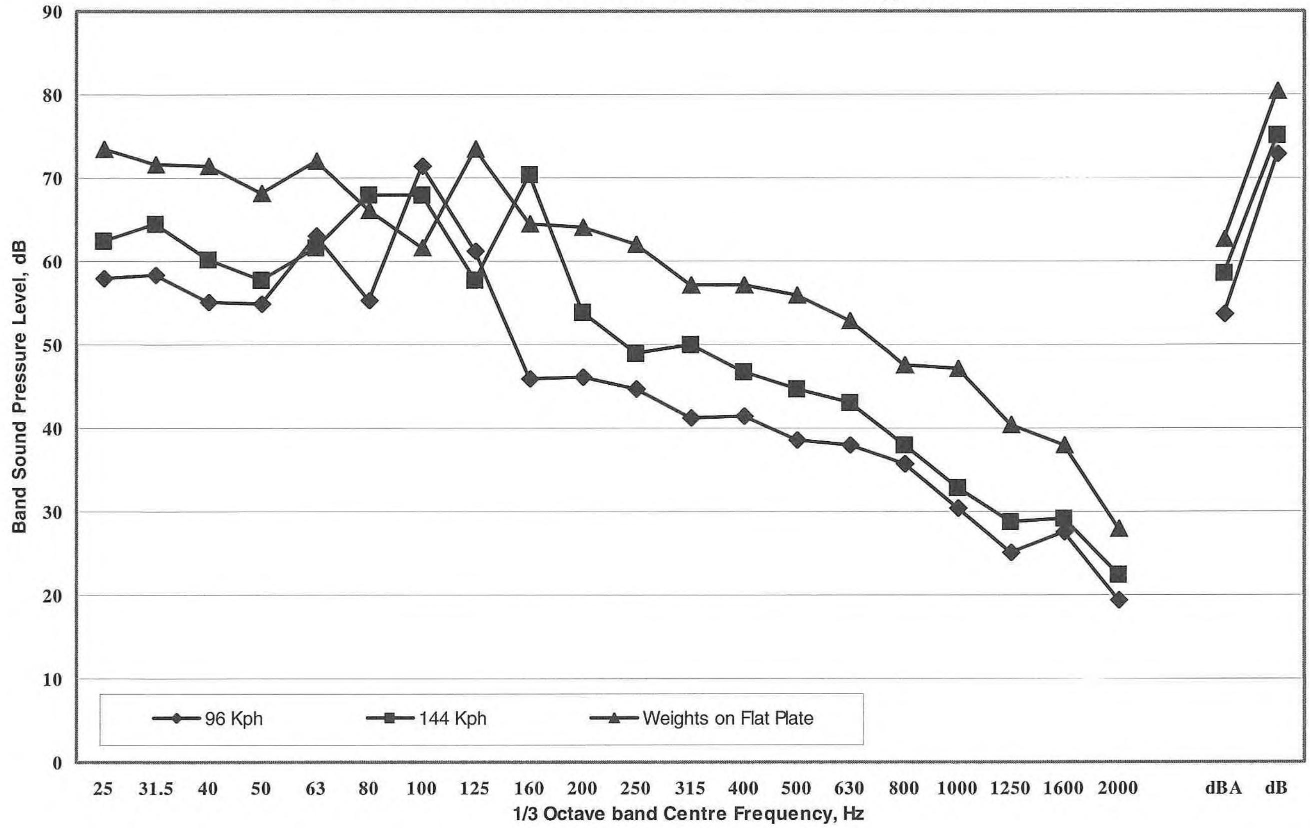
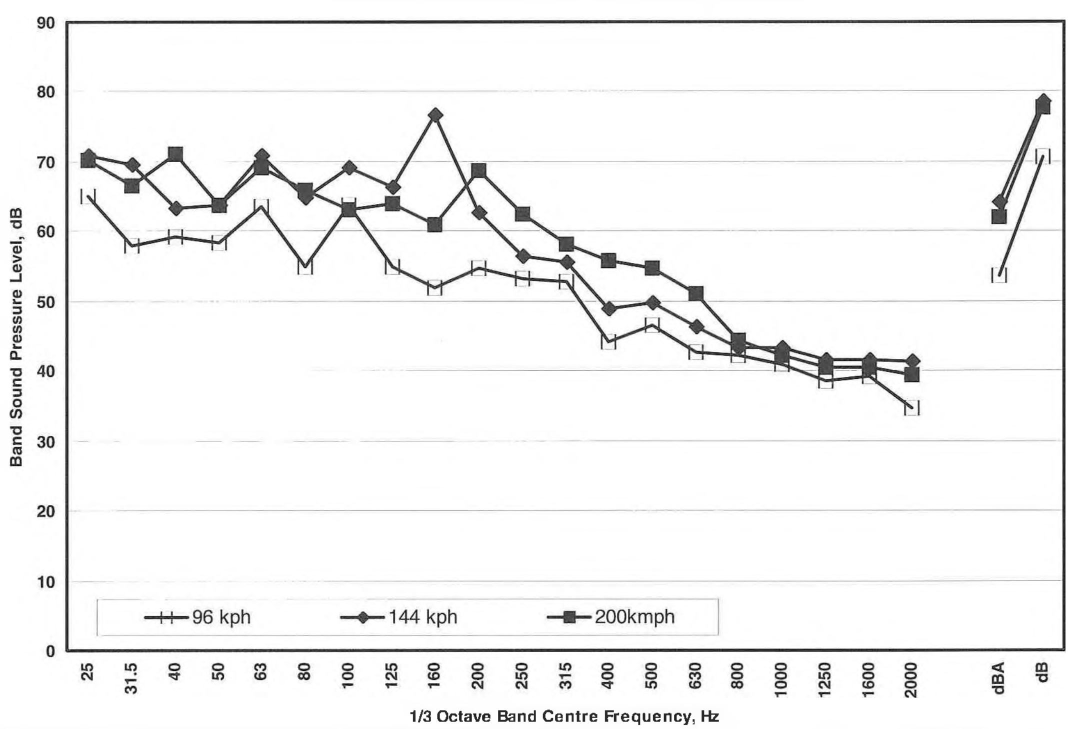


Figure 5. Control Room Noise Levels after the modifications.



4.0 FURTHER INVESTIGATIONS

The following tests were undertaken to isolate the source of the acoustic tone:

1) A one-meter thick layer of fiberglass was placed on the floor of the settling chamber, and wind-on noise measurements were repeated. The purpose of this test was to check for possible flow-induced noise from the heat exchanger, or to determine whether the settling chamber was amplifying existing noise. The results of this test (Figure 3) demonstrate that the fiberglass layer had an effect at only low wind speed, indicating that the settling chamber did not significantly impact the maximum noise levels.

b) The main fan blades were re-pitched. Aerodynamic measurements indicated that, while fan performance was satisfactory, the fan blades were not pitched to the optimum blade angle. As such, due to inefficient operation, the blades may have been subject to larger-than-normal aerodynamic forces that were driving blade resonant modes. However, with the fan blades re-pitched, no effect on the tone intensity or the wind speed at which it occurred was measured.

Attention next turned to the fan structure downstream of the rotor. For this wind tunnel, the main fan had 9 rotor blades followed by 8 stators and, downstream of the stators, a further 8 flat-plate support vanes. This arrangement of stators and support vanes is unusual due to its increased susceptibility to interaction between the unsteady wake of upstream components and downstream structures; typically, fans designed for aeroacoustic wind tunnels have only a single row of stator blades that also act as support vanes.

Visual inspection of the fan structure showed, in fact, the close proximity of the stators and support vanes in 1 or 2 locations. Impact tests showed that the support vanes had natural frequencies between 70 to 250 Hz. As a simple test, C-clamps were attached to the affected support vanes so as to modify their natural frequencies; this modification was found to reduce the noise level at the tonal frequency by more than 5 dB (Figure 4). Detailed finite element analysis of the support vanes corroborated that the vanes had transverse mode shapes at the problem frequencies.

Based on the above evidence, it was concluded that the trailing edge flow leaving the stator blades and impinging on the flat support vanes was the main cause of the tonal noise problem. The fan manufacturer was apprised of these findings and the support vanes were modified with additional ribs to change their natural frequencies. The results of these changes are shown in Figure 5 for three operating speeds. The intensity of the tonal noise has reduced substantially and the control room noise levels are within the allowable tolerance of 60 dBA at all speeds.

Note: Ramani Ramakrishnan is currently at the Department of Architectural Science, Ryerson University, Toronto, Ontario, Canada.