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GENERATING A "SILENT" FLOW OF AIR TO MEASURE THE AERODYNAMIC AND ACOUSTICAL PERFORMANCE OF A LOUVRE UNDER ACOUSTICAL LABORATORY CONDITIONS

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Abstract
National Acoustic Laboratories (NAL) has recently constructed a "silent" airflow system suitable for measuring the acoustical properties and aerodynamic performance of acoustic louvres.

A variable speed centrifugal fan capable of producing an airflow of approximately eight cubic metres per second is housed within a reinforced concrete tunnel which provides excellent attenuation from fan breakout noise. The noise generated by the fan is significantly reduced using a custom built silencer. The overall noise reduction provided by the silencer is approximately 56 dB (Lin).

Turbulent airflow generated by the system was stabilised using an air plenum in front of the exhaust duct. Regenerated noise due to air turbulence was reduced by acoustically lining the ductwork. The noise level generated by the fan and turbulence in the production of airflow was between 40 to 62 dB(A) at the entrance to the reverberation room testing chamber with an air flow of 2000 to 8500 l/s.

When assessing the performance of acoustic louvres under laboratory conditions, particular attention is given to the measurement of the air pressure and temperature of the airflow as these properties influence the rated aerodynamic performance of the louvre. The "silent" airflow has future applications at NAL in measuring the insertion loss and aerodynamic performance of silencers and ductwork.

1. INTRODUCTION

Acoustic louvres accommodate airflow whilst providing a reduction in noise. Often acoustic louvres have applications in allowing sufficient ventilation to a mechanical plant room, while reducing the plant room noise emissions to acceptable levels. However, a noise reduction will result in a higher air pressure drop across the louvre. Therefore, a balance between an allowable air pressure drop and the required noise reduction should be considered when designing noise controls incorporating an acoustic louvre. This balance is facilitated when the acoustic and aerodynamic performance has been established in a testing laboratory.

Photo 1: Acoustic Louvre undergoing testing at NAL

2. PLANT AND EQUIPMENT

NAL has constructed a concrete tube to house a variable speed centrifugal fan (18.5 kW) capable of producing an airflow of approximately eight cubic metres per second. The fan speed can be varied using belt cones and a variable speed frequency inverter. The tube has a square cross sectional area of 4 m^2, with 200 mm thick reinforced concrete walls providing excellent attenuation from fan breakout noise (See Photograph 3 and Figure 1 below).

Photo 2: Centrifugal Fan

Photo 3: Concrete Tube

Photo 4: Duct Transition

Air from the centrifugal fan is thrown onto the concrete above the fan, so a basic sheet metal turning vein was constructed (see Photograph 2) to assist in redirecting the airflow along the duct. Although the turning vein partly directs the airflow along the duct, there still exists an uneven airflow across the duct in the vicinity of the fan. Additionally, air has to turn 180 degrees after the fan silencer and another 90 degrees before entering a large 12 m^3 air plenum. The fan silencer consists of three baffles, each 5 metres long, 250 mm thick and filled with 32 kg/m^3 glasswool acoustic insulation. A smooth duct between the air plenum and exit duct with a transition area ratio of over five to one, [3] assists in stabilizing the airflow (see Photograph 4).

The straight exhaust duct approximately 20 metres long consists of duct sections each with two skins of 0.6 mm thick sheet metal separated by a 50 mm air gap filled with 32 kg/m^3 insulation. The duct connector flanges were made from 3 mm thick steel angle.

Noise measurements are taken inside the twin reverberation rooms each with five walls and hanging diffusers. The walls are constructed from 300 mm thick reinforced concrete and each room is supported on springs and dampers. The twin reverberation rooms have been certified by Australia's national laboratory accreditation authority (NATA) for transmission loss testing. The reverberation rooms and airflow apparatus are housed within a concrete shell blocking most background noise from the surrounding area. Measurements are taken remotely using a B&K Pulse multi channel noise analyser.

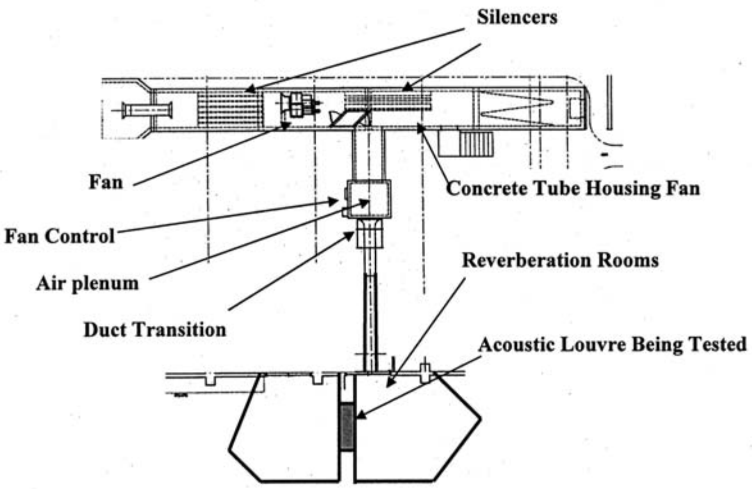

Photo 5: Test Aperture **Figure 1: NAL Testing Facility Layout**

Airflow is ducted through a custom designed door which prevents noise passing through the door from outside the testing chamber. The door is constructed from 19 mm thick marine ply, on both sides of 140 mm thick timber studs with 32 kg/m^3 rockwool acoustic insulation.

A reflective screen may be placed across the receiver testing room exit to allow airflow yet maintain a reverberant space if regenerated noise measurements are required. Additionally silencer baffles can be placed in the receiver room exit door if required.

3. AIRFLOW TEST APPARATUS DESIGN CONSIDERATIONS

Noise sources from the testing apparatus and noise paths to the testing chamber were controlled to maintain a sufficiently quiet air flow. The following subsections describe some of the noise controls encountered when designing the air flow system.

3.1 Noise Generated by the Fan and Silencer Performance

The noise generated by the fan at maximum speed inside the fan room was measured to be 110 dB. This level of noise had to be significantly reduced using a custom built silencer. The overall noise reduction provided by the silencer is 56 dB (Lin) with the octave band insertion loss values shown in Table 3 below.

Table 3. Fan Silencer Insertion Loss, Octave Band Noise Levels, dB (Lin)

	Overall, dB (Lin)	63 Hz	125 Hz	250 Hz	500 Hz	1k Hz	2k Hz	4k Hz	8k Hz
Silencer	56	32	40	45	51	52	44	45	42

3.2 Regenerated Noise Due to air Turbulence near the Fan Silencer

The regenerated noise due to air turbulence near the fan silencer was determined by subtracting the loss due to pink noise only from the loss due to fan noise including air turbulence noise. The turbulent noise was found to be contributing approximately 52 dB(A). This does not affect the noise levels in the reverberation room as the noise is further reduced by lining the ductwork downstream of the turbulent region.

3.3 Noise Emissions from the Cooling Fans attached to the Electrical Control Panel

One of the major sources of noise in the airflow system was the noise emissions from the electrical inverter cooling fans. Assuming this to be a point noise source and averaging the noise emissions at several measuring locations at a distance of 1 metre from the cooling fans, the sound power of the fans was calculated to be 71 dB(A). This noise source can be treated by installing low noise cooling fans to permanently supply the control panel inverter.

3.4 Concrete Tunnel Casing Radiated Breakout Noise due to the Fan

The sound power radiating from the concrete tunnel due to the operation of the fan was determined in accordance with [2] as shown in Table 4 below.

Table 4. Concrete Tunnel Casing Radiated Sound Power Levels in Octave Bands, dB (Lin).

	Overall, dB	63 Hz	125 Hz	250 Hz	500 Hz	1k Hz	2k Hz	4k Hz	8k Hz
Tunnel	71	86	83	73	66	58	56	53	45

3.5 Noise from Air Inlet

The sound power level of the air inlet was calculated to be 65 dB(A), [7]. This did not significantly contribute to the noise level at the entrance to the testing rooms.

3.6 Noise Intrusion into the Ductwork

The noise from the test apparatus had the potential of entering the silent airflow system through the ductwork. The ductwork exceeds the minimum recommended 1.6 mm thick steel [3]. The sound transmission loss through the exhaust duct was calculated to be 22 dB.

3.7 Noise Intrusion Through the Reverberation Room Door

A custom built door housing the ductwork was designed with a transmission loss of 45 dB, to ensure the noise level outside the reverberation room, 44 dB(A), would not contribute to the noise level inside the reverberation room during the quiet testing (low volume air flow).

3.8 "Silent Airflow" Total Noise Levels Inside Testing Chamber at Various Flow Rates

The average noise level of the "silent airflow" inside the reverberation testing room at various flow rates are shown in Table 5 below.

Table 5. Noise level of Silent Air Flow, Octave Band Sound Pressure Levels, dB (Re:20 μPa)

Flow Rate, L/s	dB(A)	63 Hz	125 Hz	250 Hz	500 Hz	1k Hz	2k Hz	4k Hz	8k Hz
0	**8**	25	15	7	-5	-5	-4	0	3
2700	**41**	42	41	38	39	38	30	-	-
4300	**53**	54	52	49	49	49	46	39	30
5700	**62**	63	60	58	57	57	57	52	44

4. MEASURING THE PERFORMANCE OF AN ACOUSTIC LOUVRE

4.1 Measuring the Acoustical Properties of an Acoustic Louvre

The louvre is built between two acoustical reverberation chambers. The transmission loss through the louvre is determined by generating pink noise in the "sending room" and taking the difference between the sound power incident on the louvre and the sound power transmitted through the louvre. Reverberation times are measured in the "receiving room" and they are used in the calculation of the sound power, [3]. The transmission loss approximates "Insertion Loss" as quoted in acoustic louvre performance specifications. Other acoustic louvre performance specifications may quote "Noise Reduction" which is the difference in sound pressure level between a reverberant space and free field. Transmission Loss or "Insertion loss" is numerically equivalent to "Noise Reduction" minus 6 dB.

Generated noise due to air "whistling" through the acoustic louvre does not normally produce a high noise level because the louvre has a large throat area compared to the typically low air flow rate. However if the generated noise through the louvre is to be determined, guidance may be sought from [3] which outlines a testing method to determine the generated noise due to the airflow in silencers. To ensure there is no background noise contribution, the average sound pressure level (with the "silent" airflow operating) is measured in the "receiving room" with the louvre (L_{pi}), and without the louvre (L_{po}) and provided the L_{pi} is greater than 10 dB above the L_{po} in all frequencies no correction for background noise contribution is applied. The reverberation time, (t)[1] in the "receiving room" is measured according to [4]. Given a room volume of (V), the sound power of the air flow generated noise of an acoustic louvre (L_w) is given in equation (1):

$$L_w = L_{pi} - 10\log_{10}(t) + 10\log_{10}(V) - 14 \qquad (1)$$

4.2 Measuring the Aerodynamic Properties of an Acoustic Louvre

The aerodynamic performance of acoustic louvres is often displayed in commercial data sheets as a graph of air pressure drop at various face velocities[2]. Appendix D of [5] sets out standard performance ratings and a testing method for determining the Discharge Coefficient (c_i) as shown in equation 2 below and the Effective Aerodynamic Area (F) as shown in equation 3 below. Five equally spaced test velocities and their corresponding pressure drops are selected with the fifth test velocity at least three times greater than the first when determining the Discharge Coefficient values.

$$c_i = \frac{q_v}{A} \times \sqrt{\frac{\rho}{2\Delta p_v}} \qquad (2)$$

Where:
c_i is the discharge coefficient for each air velocity, q_v is the air flow rate (m^3/s), A is the throat area of the louvre (m^2), ρ is the density of air (kg/m^3) and the Δp_v is the pressure drop across the louvre (Pa).

$$F = C_d \times A \qquad (3)$$

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[1] AS2460-2002 is recommended for the measurement of reverberation times instead of AS1045-1988 because the laboratory "receiving room" is altered by the air intake and exhaust openings.
[2] Face velocity (m/s) is the air volume flow rate (m^3/s) divided by the total area of the acoustic louvre (m^2)

Where:
F is the effective aerodynamic area (m^2), C_d is the discharge coefficient of the louvre which is an average of c_i taking into account uncertainties and A is the throat area of the louvre (m^2).

The airflow through the louvre may be measured using an orifice plate as recommended in [5]. However, the air flow rate determined by the "conical inlet method" based on [6] is the preferred[3] method. The test apparatus at NAL has been constructed based on [6]. Therefore, the mass flow rate (q_m) [6] in the gas sealed system is determined as shown in equation (4) below.

$$q_m = \alpha\varepsilon\left(\frac{\pi d^2}{4}\right)\sqrt{2\rho_u \Delta p} \tag{4}$$

Where:
q_m is the mass flow rate (kg/s), d is the throat diameter (m^2), ρ_u is the upstream air density (kg/m^3), Δp is the pressure difference across the louvre (Pa) and $\alpha\varepsilon$ (compound coefficient) = 0.960; when the Reynolds number is $\geq$ 300 000.

The density of air ρ_u is shown in equation (5) below based on Section 8 of [5].

$$\rho_u = \frac{3.468(p_a - 0.378 p_v)}{1000(273 + t_a)} \tag{5}$$

Where:
P_a is the atmospheric pressure (Pa), t_a is the dry bulb temperature (^0C) and p_v is the vapour pressure (Pa)

The vapour pressure p_v can be determined using equation 6 below, [6]

$$p_v = p'_{sat} - p_a A(t_a - t_w) \tag{6}$$

Where:
P'_{sat} is the saturation vapour pressure at the wet bulb temperature (t_w, ^0C) as determined from tables, A = 6.66×10^{-4} ($^oC^{-1}$) between 0 ^{o}C and 150 ^{o}C, P_a is the atmospheric pressure (Pa), and t_a is the dry bulb temperature (^0C).

The conversion from mass flow rate (q_m) to air volume flow rate (q_v) m^3/s, is shown in equation (7) below.

$$q_v = \frac{q_m}{\rho_u} \tag{7}$$

Where:
ρ_u is the air density determined in equation (5), and q_m is the mass flow rate determined in equation (4).

[3] Section 1.6.4 of [3] recommends the conical inlet method from [6] to be used for airflow measurements

5. CLIMATIC EFFECTS ON AIRFLOW

The effect of climate on the air volume flow rate is assessed using equations; 4, 5, 6 and 7 above different climatic conditions. Several flow rates are selected at standard atmospheric conditions being 20 ^{o}C, 1013.25 hPa and 50 % relative humidity. Each flow rate is calculated by varying one climatic parameter at a time with temperatures ranging between 18 and 26 ^{o}C, atmospheric pressure from 990 to 1010 hPa and relative humidity from 40 to 90 %. The calculated difference between the range in each altered parameter is given in Table 6 below.

Table 6 – Climatic effects on airflow

Standard Conditions	**Varying Temperature (18 – 26 ^{o}C)**	**Varying Atmospheric Pressure (990 – 1010 hPa)**	**Varying Relative Humidity (40 – 90 %)**
q_v, m^3/s	**Δq_v, l/s**	**Δq_v, l/s**	**Δq_v, l/s**
0.94	-10.7	11.8	0.0
2.90	-32.9	36.2	0.0
4.80	-54.4	59.9	0.0
6.62	-75.1	82.7	0.0
8.36	-94.9	104.4	0.0

6. DISCUSSION

The transition piece connecting the air plenum to the straight duct before the reverberation room, together with the air plenum itself, settled the air turbulence sufficiently for low noise airflow. It was found that although the airflow had lost velocity due to resistance in the system including duct bends and a straight section silencer, the airflow at the end of the duct was high enough for acoustical louvre aerodynamic testing. Some of the air plenum was acoustically lined with acoustic insulation with perforated metal sheet placed over the top to further silence fan and turbulence noise in the system before the air exited the duct.

Based on the flow rates in Table 6, increasing the temperature from 18 to 26 ^{o}C will decrease the volume flow rate by between 1.1 to 11.4 % compared to standard atmospheric conditions. Increasing the atmospheric pressure from 990 hPa to 1010 hPa will increase the volume flow rate by between 1.2 to 12.6 % (greater variation at lower flow rates). Increasing the relative humidity from 40 to 90 % has no significant effect on the volume flow rate.

The current airflow production is quiet enough for measuring the regenerated noise levels from acoustic louvres, however further modification to the system may be required in order to measure the regenerated noise levels from silencers in the future. In that case, several options are available to further reduce noise levels inside the airflow including acoustically lining the ductwork and air plenum area or adding an additional silencer to absorb noise (at the expense of loosing airflow) and providing turning vanes at critical air turning points along the system to reduce turbulence and regenerated noise.

Various sized throttling holes placed over the inlet or sliding plates across the air tube can be used to provide additional air resistance if a very low air flow rate is required whilst allowing the fan to run at a safe operating speed (20 Hz).

7. CONCLUSION

The acoustical and aerodynamic testing of louvres (and in the future silencers) compliments our existing world class acoustical testing facility for the development of acoustics in Australia and the world. The production of "silent" airflow and associated acoustical testing chambers at National Acoustics Laboratories is capable of measuring the acoustical and aerodynamic performance of acoustic louvres. The system has future applications in measuring the insertion loss, regenerated noise and aerodynamic performance of silencers or lined ducts.

Noise controls to generate the "silent airflow" were designed to firstly treat the loudest noise source, the airflow fan, using a substantial concrete tunnel housing and five metre long fan silencer in order that secondary noise sources such as air turbulence noise and external cooling fans could be treated easily depending on their respective noise levels.

When assessing the performance of acoustic louvres under laboratory conditions, particular attention is given to the measurement of the air pressure, temperature, in the airflow as these properties influence the rated aerodynamic performance of the louvre.

The correct acoustical and aerodynamic performance data will allow the correct design of noise controls that incorporate acoustic louvers. Acoustics and aerodynamics have to be considered in conjunction with each other for an optimal acoustical design incorporating acoustic louvres.

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