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Aero-Acoustic Assessment of Façades

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Abstract

The Adelaide Medical & Nursing Schools project will be a new campus facility at the west end of North Terrace, forming a clearly identifiable new presence for the University of Adelaide in the State's developing Biomedical Precinct. This 17 storey building will house sensitive research spaces and is located between the main rail corridor and main road into Adelaide's CBD. Previous work by the architect on similar research facilities in Victoria highlighted the risks of wind generated noise from novel facades. Novel facades are now becoming the norm, with fixed or operable elements used for shading, and the façade often decorated to create interest. This paper will highlight a novel technique developed to assess the potential of a façade to generate noise from wind impacting the façade.

Introduction

Noise generated from wind impacting façade elements has received increased attention in recent years. The most notable example is Europe's tallest residential building in Manchester, England, known as "Beetham Tower", which received widespread publicity when completed, refer to Figure 1 as reported by Leeming (2006):

Tallest tower whistles in the wind

EXCLUSIVE
by Ciara Leeming

EUROPE'S tallest residential building has been hit by a costly design flaw which causes the landmark tower to whistle loudly in the wind.

Project managers at the £150m Beetham Tower, which now dominates the Manchester skyline, have called in experts to suggest a cure for the noise before doors open later this year.

The first residents of the 47-storey tower are due to move in during the autumn but may demand compensation or alternative accomodation if the sound is judged unbearable.

People living in nearby streets have already reported hearing a loud humming noise through their closed windows, which some believe may be coming from the multi-million pound tower.

The flagship development, on the crossroads between Deansgate, Great Bridgewater Street and Liverpool Road in

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Figure 1 Article from The Enquirer –North West, from Leeming (2006)

It has been recently reported by Baker (2015) that work to reduce or eradicate the noise took place with foam pads installed in 2007, aluminium nosing in 2007 and further undisclosed work carried out in February 2010, but attempts to eradicate the noise permanently have been unsuccessful.

Ploemen at al (2011) also provides evidence of two tall buildings in the Netherlands which became notorious for noise generated with winds speeds of around 12-15m/s. The source of noise was purported to be steel grids as shown in Figure 2.

Figure 2 From Ploemen et al (2011), Het Strijkijzer, The Hague (130m), completed in 2007 (left) and De Hoftoren, The Hague (110 m), completed 2003 (right).

Other recent and local examples include aeolian noise generated by the finned balustrade of freeway pedestrian overpasses installed at 6 locations along the 40km Eastlink project in Melbourne, Australia (Mitchell et al, 2009). Noise levels at nearby residential properties were reported to be 40dB greater than the background (or ambient) noise level.

The author previously experienced similar levels of wind generated tonal noise from a louvered sunshade above the penthouse level balcony, with the louvres consisting of equal-angle steel sections facing downwards and spaced regularly.

Previous Work

Rofail and Tonin (2000) first introduced the issue of "wind-noise" in buildings, with measurements carried out with flow through an open window/door with recesses in Aluminium extrusions as per Figure 3.

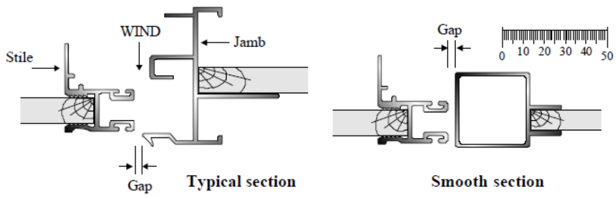

Figure 3 Wind generated noise from accelerated flow across a cavity

Moloney et al provided a general discussion of testing and assessment of wind noise around buildings which briefly discussed aerodynamic noise sources (eg. Vortex shedding, cavity resonance, structural resonance) and potential issues with building elements (eg. Cables, slots, etc). Test facilities rather than computational methods were introduced to identify problems with building elements.

Coppa and Paduano (2015) describe a design process to evaluate the potential of wind noise at façade elements using computational fluid dynamics (CFD). Vortex shedding from sunshade elements is demonstrated through CFD by calculating the power spectral density of the time trace of the pressure coefficient. There is some discussion on "lock-in" phenomena or coincidence of vortex shedding with acoustic resonance, but no definition of the radiated sound power level. Also outlined by Coppa and Paduano is Arup

Acoustics guidance notes that have "never been fully tested or studied extensively" and have been "too often deemed impractical and unreasonable from an aesthetic and façade engineering standpoint", refer to Figure 4.

Elements-aperture	Dimension	Comments
Unsealed slots, apertures and exposed elements within façade cladding	>100mm	For exposed elements introduction of vibration damping treatments needed. For cavities and apertures it is recommended to close all openings and apertures to avoid the creation of resonant cavities.
Wires, circular cables, tubular elements or hollow sections	>50mm	If a bigger dimension than 50mm is not possible to be included then provide special damping treatment.
Array elements	>100mm	In case of regular array of elements, smaller dimension of apertures should be avoided or provide special damping.
Constructions	>100mm	Irregular constructions should be used to break-up vortex street formations.

Figure 4 Arup Acoustics guidance notes (Coppa and Paduano, 2015)

Coppa and Paduano's work also highlighted the importance of flow parallel to the façade. Fricke (2010) initiated some work on local façade velocity estimates, as shown in Figure 5, with local peak (3 second gust) velocities at the roof edge up to 1.7 times the incident peak velocity. Mean and peak wind speeds and multipliers to account for directionality, topography, terrain and the like are well established in building codes such as AS/NZS1170 which are not ordinarily recognised nor understood by acoustic consultants.

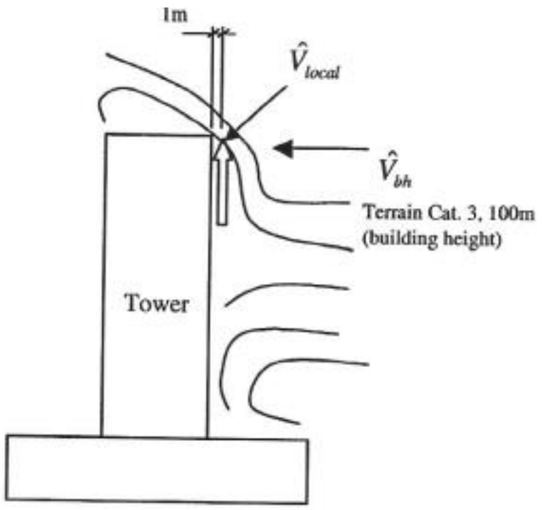

Figure 5 Velocity of wind across a façade relative to the incident velocity at building height

There is a strong overlap between acoustic and wind engineering, with recent developments in the assessment of noise from wind farms instigating improved understanding of aerodynamic sound concepts (as well as an understanding of meteorological conditions and models usually associated with air quality and dispersion analysis). The study of aerodynamic sound began with noise from jets, Lighthill (1952,1954), and was developed within the domain or aerospace (high mach numbers) and mechanical (low mach numbers) engineering. Lighthill rearranged the Navier-Stokes equations governing fluid flow (conservation of mass, momentum and energy) into a wave equation describing the acoustic field generated by turbulence.

Aerodynamic Noise Sources and Aeroacoustics

Noise generated from fluid flow is called aerodynamic sound and is considered within the field of aeroacoustics. Subsonic flow can be classified into three source types:

- Monopole : Produced by pulsating flow or flow that causes pulsations such as flow over a small aperture in a wall, with the flow inducing pulsating motion of air in the aperture. The radiated sound power is given by:

$$W \propto \frac{\rho L^2 U^4}{c} \quad (1)$$

- Dipole : Produced when flow interacts with surfaces or bodies, such as vortex shedding from aerofoils, cables or similar. The radiated sound power is given by:

$$W \propto \frac{\rho L^2 U^6}{c^3} \quad (2)$$

- Quadrupole : Produced by Reynolds stresses in a turbulent flow, such as that of a jet or the turbulent boundary layer over a flat plate. The radiated sound power is given by:

$$W \propto \frac{\rho L^2 U^8}{c^5} \quad (3)$$

The radiation efficiency of dipoles and quadrupoles is less than that of monopoles due to phase cancellation of pressure pulsations.

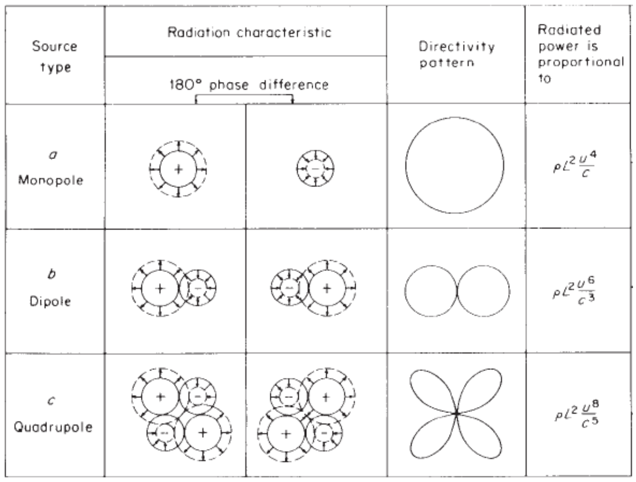

Figure 6 Aerodynamic noise source types.

As an example, sound pressure levels measured by Rofail and Tonin for flow exciting a cavity resonance (refer to Figure 3) is shown below in Figure 7, with the change in sound pressure consistent with the 4^{th} power of the velocity ratio suggesting the aerodynamic noise source is of monopole type.

Sound pressure levels measured by Akagi et al (1998) for Aeolian tones generated from vortex shedding of power lines are given in Figure 8, with the change in sound pressure level with doubling of the wind speed consistent with the 6^{th} power of velocity suggesting the aerodynamic source is of dipole type.

Analytical Methods

These relationships are important as they give an insight into the level of velocity required to generate specific noise levels (which links to level of occurrence of those velocities). Similarly are methods to estimate the frequency of tones generated by vortex shedding or cavity resonances.

Analytical methods have been developed simple forms such as flow interaction with simplistic objects, flow over cavities etc, but a semi-empirical approach is often used to estimate the frequency and intensity of the acoustic field generated by such flows.

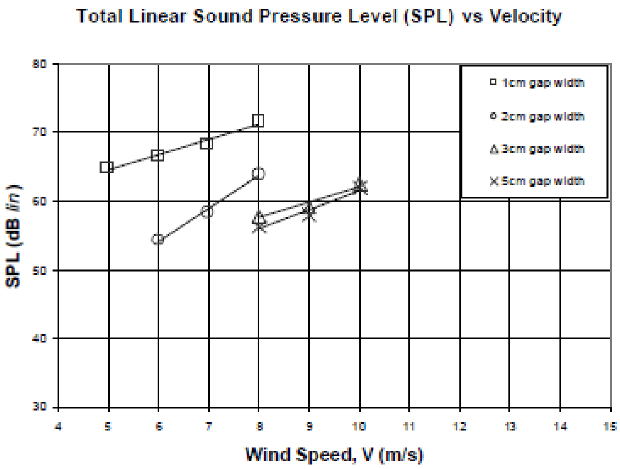

Figure 7 Measured sound pressure levels with flow across a cavity

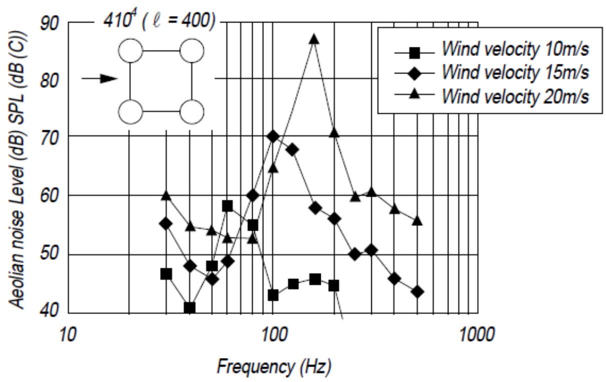

Figure 8 Aeolian noise generated from a 4-bundle conductor (Akagi et al 20xx)

Numerical Methods or Computational Aeroacoustics

As described by de Jong (2008), computational or numerical methods have traditionally used finite elements to solve the Navier-Stokes and Lighthill equations. More recently (the last two decades), rather than solving these equations a simplified method known as the Lattice Boltzman Method (LBM) has been developed and commercialised as a form of computational fluid dynamics software. It uses a microscopic approach applying conservation of mass, momentum and energy to particles moving in a lattice structure. It is similar (though more complex) in some respects to ray-tracing in acoustics which simplifies the wave equation to model acoustics within enclosed spaces.

De Jong demonstrates the ability of LBM to accurately predict the frequency and intensity of sound generated by hydrodynamic and acoustic feedback mechanisms, as well as acoustic resonance similar to the situation encountered by Rofail and Tonin and shown in Figure 9. This simulation shows the ability of LBM to simulate the effects on noise generation of alternative layouts, forms of blades and surface treatments. The effectiveness of a simple surface irregularity to disturb the flow prior to the cavity was demonstrated by de Jong (the method used by the author to resolve wind generated noise from a louvered sunshade).

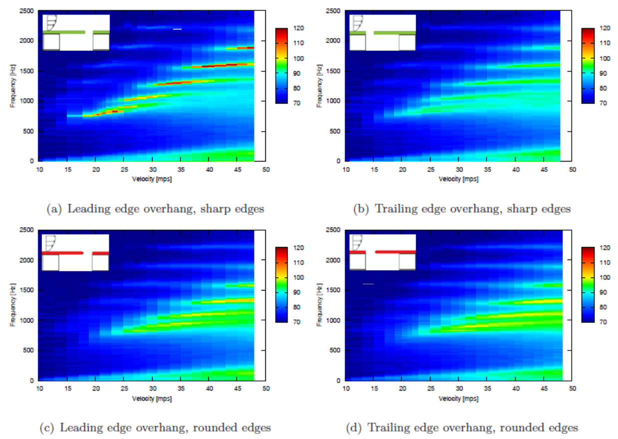

Figure 9 Spectograms of sound intensity relative to frequency and velocity of flow over a cavity with differing boundary conditions

Wind Tunnel Test Methods

It has become customary to test full-scale façades or elements as shown below in Figure 10 (Ploemen et al, 2011) to assess their potential for wind generated noise (or assess the cause of the noise post construction). As noted by Ploemen, two types of tones were measured, type I which increased in frequency with increasing wind speed, and type II which had a constant frequency but increased intensity with wind speed. The mechanism behind these types of tones was not defined through wind tunnel testing.

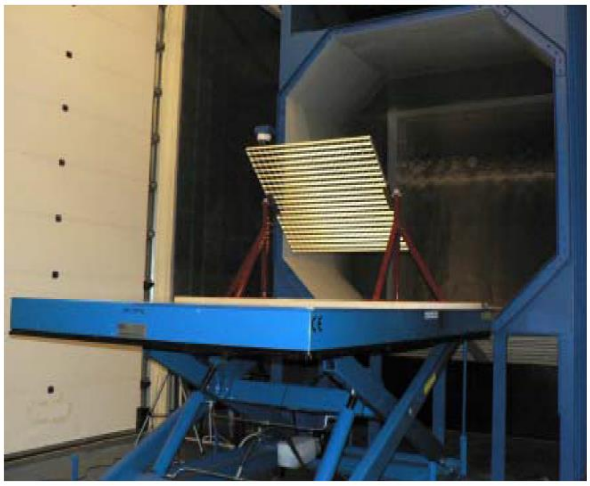

Figure 10 Wind tunnel test setup of façade element

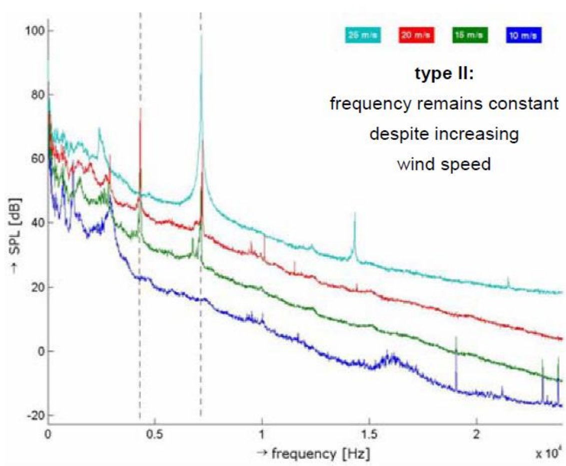

Figure 11 Measured noise levels from test rig

Case Study

A case study will be presented for the University of Adelaide's new Medical and Nursing School building located on North Terrace, along-side the main rail corridor into Adelaide. The building is shown in Figure 12, with a relatively complex façade. Return period wind speeds were initially assessed to understand the occurrence of given wind speeds. CFD was used to assess wind flow across the façade as shown in Figure 12. Semi-analytical methods were used to assess the potential for wind generated noise, which were later tested inexpensively in a factory rig with a quiet fan and spun nozzle, shown in Figure 14.

Figure 12 University of Adelaide's new Medical and Nursing School.

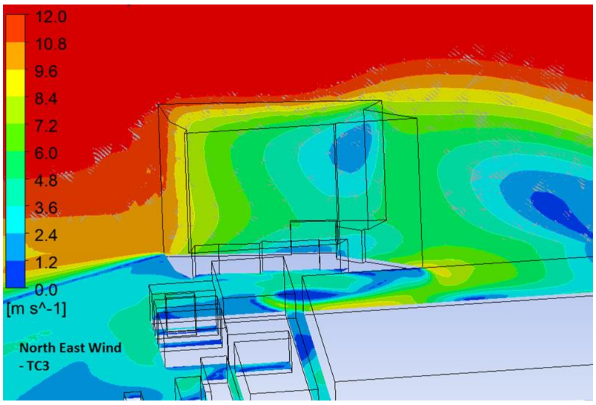

Figure 13 CFD model of the building simulating wind from the North-East to assess wind speeds across the face of the façade.

Conclusions

This paper has highlighted a number of different approaches that are available for building sciences engineers to assess the potential of a façade to generate noise when impacted by wind, and the occurrence, frequency and intensity of this noise.

Acknowledgments

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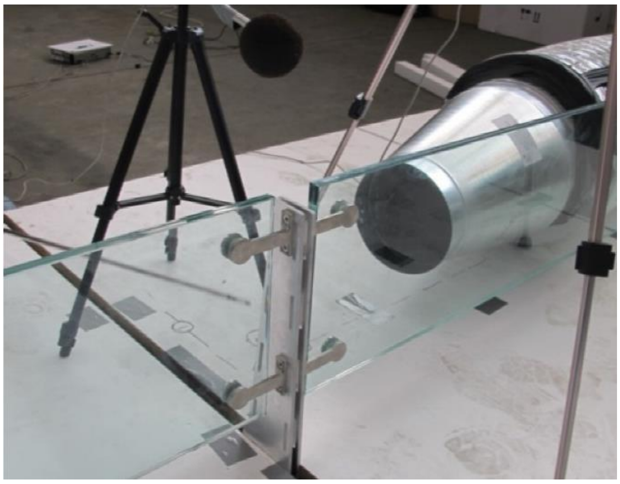

Figure 14 Test-rig setup to measure aerodynamic noise

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