TESTING AND ASSESSMENT OF WIND NOISE AROUND BUILDINGS

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Abstract
This paper presents a discussion of the problem of wind generated noise. Example problems are presented and some methods of testing for wind noise are shown. Methods for the assessment and relative annoyance of noise making building features are discussed. The aim is to highlight the increased incidence of wind noise as a problem in modern building and provide some discussion of how to prevent, treat and assess these noise problems.

The Problem of Wind Noise around Buildings

In recent months the issue of wind generated noise has presented some problems for residents in various Melbourne City buildings. Some noise problems have been encountered for completed building projects where the issue of wind noise was never considered. On site, these building elements were producing a daily noise annoyance with strong tonal character causing residents to lose sleep. In addition there was some indication that these wind noises drew increased attention to the windiness of the location and increased the perception that the site was windy. In other cases some building elements were identified as potential noise generators and were tested in the wind tunnel prior to construction. The various building components tested by the authors recently have produced a range of wind generated noises from whistling, to metal-on-metal vibration and white noise.

Modern architecture is increasingly using lightweight, narrow section and porous members both structurally and for artistic purposes. These sorts of components are prime suspects for generating annoying noises when placed in windy environments. The role of the wind engineer in these cases is to foresee the potential problems with such components and devise tests to ensure all wind noise issues are controlled prior to construction of the building.

During Vipac's laboratory testing, assessments were made to determine the likely perceived annoyance and/or acceptability of the measured noises. Once the conditions for tone generation were discovered, we determined whether the noise could be transmitted through to the building occupants, how often it would occur and the need for remedial action.

Limited information and research exists on the testing and assessment of wind noise around buildings. Related research to date has mostly concentrated on blade pass tones from wind turbines and the aeroacoustics of automobiles.

Types of Wind Noise Problems

Many of the wind noises around buildings occur as a result of fluctuations in the pressure or velocity field. The fluctuations produced can excite audible resonances in structural components or produce waves which themselves become audible. Some well known noise mechanisms worth noting include:

Aeolian Tones – these occur when there is high frequency vortex shedding such as in the wake of a cable or an aerofoil or by flow separation off a sharp edge.

Helmholtz Resonator – this is a volume of air which periodically increases and decreases in pressure. For long and narrow air columns such as pipes, the resultant fluctuations can be amplified and vibrate at an audible tone governed by the pipe length.

Structural Vibration – the motion of various building components in the wind can often result in friction between elements and this can be an annoying form of wind noise.

Shear Layers –friction between air boundaries and/or increased velocity such as though narrow gaps between buildings can often produce broad band noise audible as "howling".

Identifying Potential Problems

With the above mechanisms in mind, some of the potentially noise making building elements that wind engineers can look out for include the following:

Tension Cables – Some of these are known to produce Aeolian tones with frequency dependant on the diameter of the cable The wind velocity (U) for onset of noise at a given frequency (f) can be estimated using a Strouhl number of around 0.2 [Parker 97]

$$S = f.d/U$$

Flow through Narrow gaps such as windows and doors. The onset of whistling between gaps can occur for Strouhl numbers of between 0.8 to 1.4 with tones produced for wind velocities of around 7m/s. [Rofail 00}
Flow across a hole – For the case where a hole leads to a volume of air, these can set up resonance within an air column. The combination of narrow gap or hole and an air column is one found in many musical instruments and can occur on buildings in window frames, hollow section sun shades, open ended structural members and drainage gaps in a façade.
Flow across sharp edges – Parker (REF) demonstrated that tones caused by separation off a flat plate could be purely acoustic and independent of the natural frequency of the edge obstruction.
Flow through screens –some screens have regular patterns with perforations which produce vortex shedding. The combination of many vortices can setup complex resonance in the screen itself and produce Aeolian tones.
Dynamic or flexible facade elements – these can have high natural frequencies in the audible range or can produce audible frictional vibrations.
Fluctuations in the pressure field – for areas of high turbulence, high frequency fluctuations in the pressure field around a building can produce resonance within pockets of air. This effect is well known as drumming in an automobile with one or two windows down.
It is worth noting that some combinations of these elements can produce even greater tonal characteristics.

Testing for Wind Noise

Laboratory testing can be carried out on full-scale components of a building and/or representative sections to predict the likely occurrence of wind noise. Of cautionary note is the need to adequately simulate the approaching scale and intensity of turbulence in the approach stream and the relevant natural frequencies (and support constraints) of the element as these can act intimately with the flow frequencies to produce noise.

Some methods of computational aero-acoustics exist for assessment of wind noise, these seem mostly limited to simple 2-d problems and vehicle acoustics for which experimental data is readily available but such methods may be expected to flourish in the future. Numerous aero-acoustic facilities exist around the world, typically for automotive testing. Standard practice is to subtract the system noise from measured data.
Methods of testing for wind noise include but are not limited to:

1) Wind tunnel testing –environmental wind tunnel facilities and/or aero-acoustic facilities would appear to be the most suitable method of testing full scale (and model scale) prototypes. A noisy wind tunnel can still be used to test for tonal noise generation off building components although it can be difficult to quantify the magnitude of the noise without adequately moderating the ratio of signal to background noise. A wind tunnel is advantageous because the experimenter can immerse the entire sample in the flow and also achieve good simulation of the approaching turbulence. Pin-pointing the noise source can be troublesome and some researchers have used stethoscopes to listen more closely to the wind.
2) Quiet Air Supply – When it is necessary to measure the noise output from a building feature, it is useful to use a quiet air supply or an aero-acoustic wind tunnel. A danger exists in using flow which is too steady because it may not trigger the correct noise-making wake conditions. Care also needs to be taken to simulate the pressure field imposed on the sample during site conditions. The advantage of a quiet narrow jet is to isolate the noise making area making it more easily identifiable.
3) Pressure Chamber – a standard air leakage test can sometimes identify noise problems associated with whistling through openings in the façade. The literature indicates that the onset of noise through narrow rectangular slits can occur for pressures of around 450 to 500Pa.
4) On Site Assessments – allow exact measurement of noise levels and (limited) prediction of noise at different wind speeds and directions. This method also allows measurement of the impact of wind noise within and around the building. It is easy to miss some critical conditions with this method.

We note that many of these techniques are complimentary and some of the testing techniques may inadequately simulate the on-site condition. In predicting the occurrence of wind noise, it is most important to accurately simulate the approach wind condition (wind direction, turbulence etc) and the fixing condition of the component under test.

Assessment of Wind Noise and Annoyance Criteria

Noise criteria in offices and apartments are well established in terms of peak levels and overall equivalent time averaged levels (Leq). There is also a lot of literature about the annoyance of noise and the field of "psychoacoustics". Of note is the fact that unwanted natural tones are deemed more annoying than the equivalent loudness of white noise.

In the field of psychoacoustics, the governing parameters for noise annoyance are volume, frequency (tone), and duration. There is also the effect that the source of the noise can cause people to object to its nature (ref www.windpower.dk). Some research has been carried out by Vipac in the area of psychoacoustics relating to air conditioner noise to predict the human response to daily white noise, the results of this study indicated that low frequency rumbling is much more of a concern than higher pitched air flow noises.

In the opinion of the authors, from anecdotal evidence, the occurrence of wind noise in all forms (howling, white noise, whistling) can potentially make an environment seem windier than it would otherwise be judged by standard wind gust comfort criteria. Some future research may be necessary to determine the effect of the noise of the wind on the perceived human comfort in the environment.

For the assessment of whether a particular wind noise should be deemed a problem the authors can suggest the following methods of analysis:

1) Determine the internal or external noise criteria. These may be an overall noise rating (NR) or an overall A-wt equivalent (8hr average) sound pressure level in a room. Without specific wind noise acceptability data, the criteria may be determined from a combination of traffic noise, aircraft noise and wind turbine noise acceptability.
2) For external sources determine/measure the sound power level (Lw) from the component. Sources internal to building elements may require measurement of the sound Pressure level (Lp) in the cavity.
3) Use an area averaging technique or similar addition method to account for the combined effect of many façade components making the same noise. Calculate the overall sound power level.
4) Calculate the sound reductions through each possible transmission path including through windows, air columns from the façade into the building and any structure borne noise.
5) The noise data must be combined with wind data to determine the return period of the noises and the resultant acceptability to occupants.

Remedies for Wind Noise Problems

Research and recent experience suggests that the solutions for control of wind induced noises are not always easy to implement. Prevention by identifying potential problems is the best method rather than post installation fixes. This type of solution requires an understanding of the cause of the problem and some of the causes suggested above will serve as a guide. Our recent experience has shown that methods such as blocking the wind source does not always work especially where changing the velocity conditions does not significantly change the local pressure conditions. Some typical noise control remedies include the following:

1) Baffling the wind flow path – the most obvious method of this is by blocking off holes and sealing gaps. In addition the use of trees and screens (non-noise making variety) can reduce the wind speed to below the critical levels for noise making.
2) Increase or decrease the gap width or hole dimension. There tends to be a critical gap width which produces tones.
3) Altering the wake by affecting separation for example by modifying the trailing or leading edges of the component.
4) Adding Damping elements –including deadening paints to vibrating components, these can completely abate some resonant noise sources.
5) Introduce more background noise – externally, trees can increase the level of acceptable (white), background noise so that the noisy building component is drowned out.

Finally, by some wind data analysis and consideration of the typical wind flow patterns around the building, it may be deduced that the frequency of occurrence of the noise is so small as to be considered acceptable.

Example Problems

Example 1 Singling Carpark Panels

The authors recently tested a porous metal panel which was in use as a carpark screen on levels 2-4 of a 27-storey building. On site, the panel was observed to produce strong resonant tones during only moderate breezes. The tonal character of the noise was particularly annoying. Interestingly the noise seemed more prevalent for flow out of the carpark rather than into it. Measurements of the noise were made on site during a strong to moderate breeze. A sample of the carpark panel measuring approximately 2.5m X 1.5m was tested in Vipac's lab. The panel is perforated with circular holes of 5mm diameter punched into the 5mm thick aluminium plate at 10mm centres with each row offset by one hole diameter from its neighbouring rows. Initially the panel was set-up in the wind tunnel (a noisy environment) with indicative support conditions and the tone of 5kHz was reproduced above 7m/s. It was

observed that the tone could be stopped by placing an open hand on the panel. Reducing the wind flow onto the panel such as by a baffle did not necessarily stop the whistling.
When the panel was tested using a quiet air jet of around 200mm diameter there was no whistling produced from the holes. It was deduced that the mechanism of wind noise in this case was that of Aeolian tones produced by vortex shedding through the perforations. The fluctuating pressure behind each hole then produced a resonance in the entire panel itself. Numerous solutions were proposed and trialed for this panel however the most effective method turned out to be the cheapest. A layer of sound deadening paint was applied to the screen, allowing air flow through the panel while providing dampening of the high frequency vibrations.

Example 2 Vibrating Artwork

A piece of artistic building façade was identified as a potential noise maker because of its narrow gaps and sharp edges. This carpark screen panel featured 200mm square "leaves" cut on three sides and punched out to a specified angle from a square aluminium sheet. The leaves were pushed out to leave gaps of between 1 and 70mm. The panel was tested with a quiet, narrow air jet to test for whistling and no significant tonal noises were observed for any combination of wind angle, velocity or gap width. The sample was then tested in the wind tunnel with blanking surrounds. The interesting discovery that arose from the wind tunnel testing was excessive vibration of the leaves and subsequent noisy friction against the panel. The testing showed it was necessary to increase the width of the cut while ensuring there would be no whistling through the new gaps now introduced.

Example 3 – A Noisy Façade.

A section of façade for a tall building in Auckland was tested using a quiet air supply and several significant tone events were discovered. The sample was held in a rig with adjustable angle and a quiet air jet was blown across the entire width (approx 1500mm square) of the façade sample. Wind speed was adjusted over a typical once per week (gust) to once per month range. A microphone was inserted into the façade mullion to measure the airborne noise thorough the mullion and predict the subsequent transmission into the building. A microphone at one meter from the sample was also used to determine the sound power from the façade element and then the transmission through the windows etc. The mechanism of wind noise in this case was high frequency vortex shedding of the sharp edges of the façade; the tone was enhanced and controlled by resonance of the air column within the mullion. Tone amplitudes of 110dB broadly centred at 125Hz were observed for a 15m/s wind speed. Interestingly when the sample was loaded under differential pressure (in a pressure box) there was no tones produced, this implied the dependence on flow velocity and induced fluctuations in that flow for the noise generation. This case highlighted the need to identify the condition of noise making, take measurements to ascertain the noise path and then combine wind speed data with noise level criteria to decide if the noise would be a problem or not. The most convenient solution to the problem turned out to be the use of baffles inside the framing members.

Conclusions

The recent experience of the authors has highlighted the increased incidence of wind noise as a potential annoyance for building occupants. Some discussion has been presented of the testing and assessment of these wind noises. Generally the advice from this work is to:

1) Think wind noise and identify the potential noise sources on buildings such as narrow gaps on the building façade, porous screens,
2) Carry out testing to determine the conditions for the on-set of wind noise, this could require two or more methods of testing. Determine the mechanism of wind noise generation.
3) Establish some noise criteria based on noise limits inside the building and outside. These need to related a return period in order to be correlated to the wind.
4) Calculate transmission losses etc under the design condition to determine if there is a noise problem.
5) Take remedial action by testing

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