Comparison of hot film anemometer and bran erosion techniques used in wind tunnel studies to assess the pedestrian wind environment

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Introduction

This paper reports a systematic comparison of hot film anemometer and bran erosion techniques used in wind tunnel studies to assess the pedestrian wind environment. The aim of this research was to determine the reliability of inferring relevant and accurate wind speeds solely through bran erosion tests. At a minimum it was expected that the research would define the loss of precision associated with the erosion technique.

Research Method

Wellington City has required a wind tunnel test of every new building proposal taller than 4 storeys in the CBD since the early 1980s. Because the city requires that these tests submit flow visualisations and anemometer readings a large number of professional wind tunnel reports (most conducted by Opus Central Laboratories) are on file. A comparative study of these tests permitted an efficient gathering of data for correlation studies, and made available a large quantity of data in which an array of different aerodynamic situations and locations could be 'tested'.

Previous attempts to infer wind speeds from erosion tests (Beranek,[3] Livesey[4] and Durgin[5]) use a rectangular block/s or a typical city block for the model in which comparisons between the two techniques are made. A series of erosion measurements are made and compared with measured wind speeds. This research differs from these standardised approaches in three areas:

1) It evaluates a comparatively large number of measured points and erosion tests.
2) The data is extracted from many different wind tunnel simulations conducted with professional accuracy for code compliance. Each project report typically has 2 design situations, erosion tests for 4 wind directions; and anemometer based wind speed measurements at 25+ positions.
3) These tests include many different urban situations throughout Wellington City; none have standard heights of surrounding buildings. None are 'typical'. All are representative.

Thirty wind tunnel reports have been analysed, providing over 3000 individual points of comparison. The types of urban locations in which measurements are conducted vary considerably, thus, assessing a broad spectrum of urban wind flow characteristics. Each report has a number of contour images produced as a result of bran erosion measurements. An example of a contour diagram is shown in figure 1. The level of contouring (windiness) represents 2 minutes of erosion at a specific wind tunnel speed in a boundary layer wind tunnel. The wind tunnel speed is initially relatively low and is incrementally increased over a period of 20 minutes. The earlier erosion occurs, the higher the windiness level. A direct comparison has been made between the level of contouring present at points at which a hot film anemometer measurement was taken (see figure 2).

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[3] Beranek, W.J., Van Koten, H., (1979) Visual Techniques for the Determination of Wind Environments, *Journal of Wind Engineering and Industrial Aerodynamics.* (4) 295-306.

[4] Livesey, F., Inculet, N., Isyumov, A.G., Davenport, A.G. (1990). A Sour Technique for the Evaluation of Pedestrian Level Wind Environment. *Journal of Wing Engineering and Industrial Aerodynamics.*(36) 779-789.

[5] Durgin, F.H., (1992) Pedestrian Level Wind Studies at the Wright Brothers Facility, *Journal of Wind Engineering and Industrial Aerodynamics.* (41-44) 2253-2264.

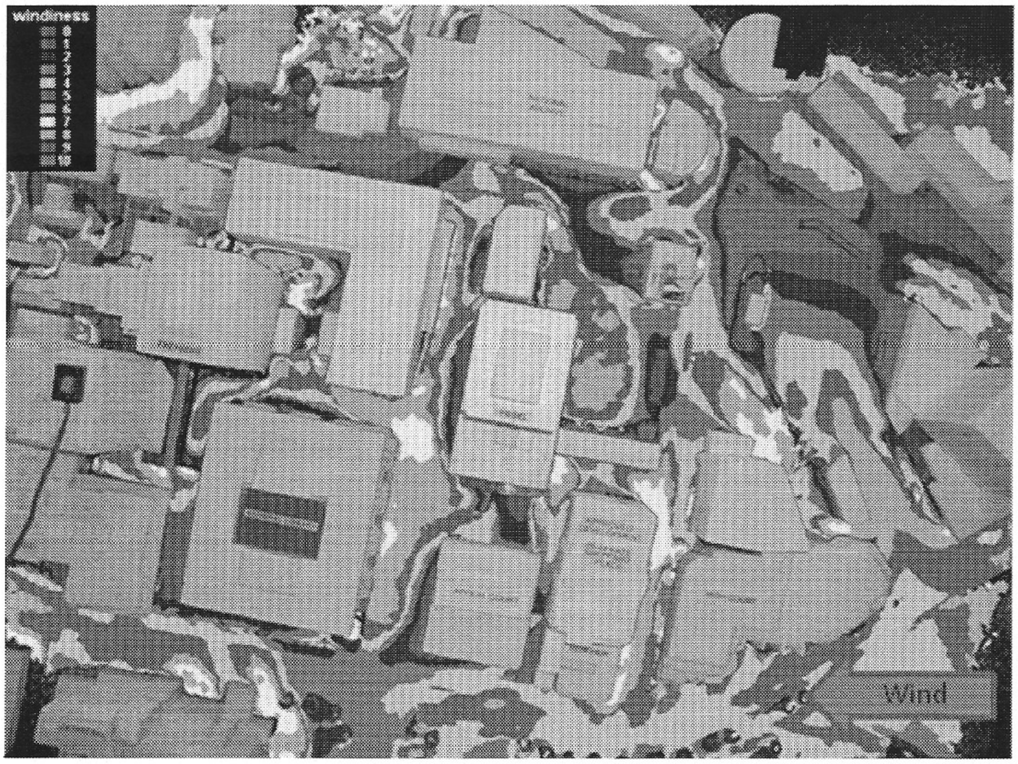

FIGURE 1: Contour graph produced as a result of bran erosion testing.

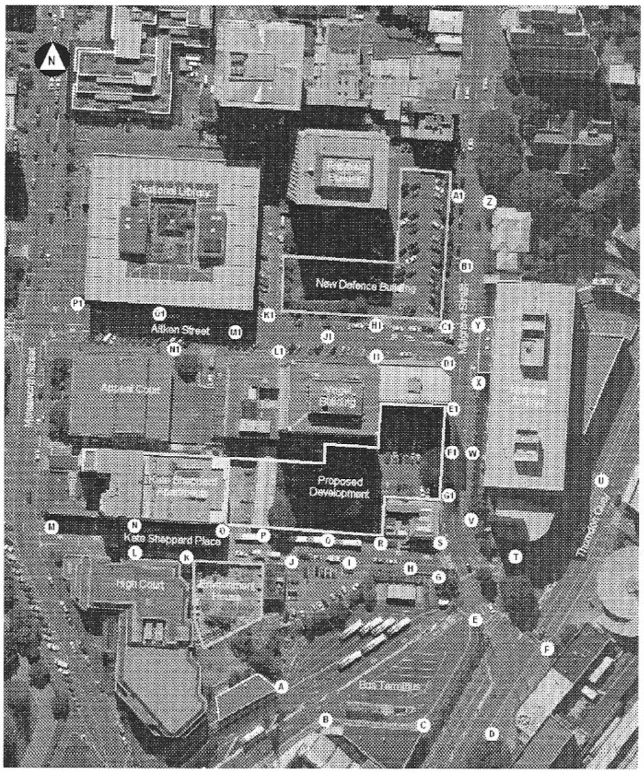

FIGURE 2: Locations at which hot film measurements were taken.

The Relationship of the Wind Speed Measurement to Wind Contour Level

The wind speeds were graphed against windiness level. The goal was to determine the spread of data at each of the windiness levels. In order for the data from erosion contour tests to replace the data from the wind speed measurements there must be a reasonably narrow distribution of data at each windiness level. Determination of how narrow is 'reasonably narrow' requires identification of an acceptable margin of error in decisions based upon this method. For the analysis the median wind speed at each level of windiness was determined and the spread of the spread of data above and below this line was calculated. Opus Central laboratories currently assess wind speeds through hot film anemometer testing with a margin of error – a repeatability - of 1m/s. Typical measured speeds are around 13 m/s. To match this, the majority of the results would need to lie within this narrow margin.

Different measurements of wind speed were compared to the "windiness" level. This would potentially identify the component of the wind that is being measured by the bran erosion tests. The components of wind speed that were analysed were: mean; maximum; calculated maximum; standard deviation; and effective gust speed. The maximum speed is the maximum single gust speed measured at the individual point. The calculated maximum is calculated by $V_{calmax} = V_{mean} + 3.7V_{rms}$, where V_{mean} is the mean speed, and V_{rms} is the standard deviation. The factor 3.7 is the peak factor corresponding to a wind speed that is occurring less than 0.1% of the time. The effective gust is calculated by $V_{eff} = 1.3(V_{mean} + 2V_{rms})$.

Figures 3, 4 and 5 show respectively the distributions of the mean speed, standard deviation and the calculated gust versus windiness value. There is a steadily increasing trend in all three results. That is, it is reassuring to note that the windiness level increases as the overall measured wind speeds increase. Although this is the case overall, none of the components of measured wind speed that were compared to a windiness value produced a reasonable correlation. The calculated maximum showed the best correlation at 0.59, while, the standard deviation showed the worst at 0.53. In order to determine a reasonable wind speed measurement, a correlation coefficient of at least 0.9 would be required.

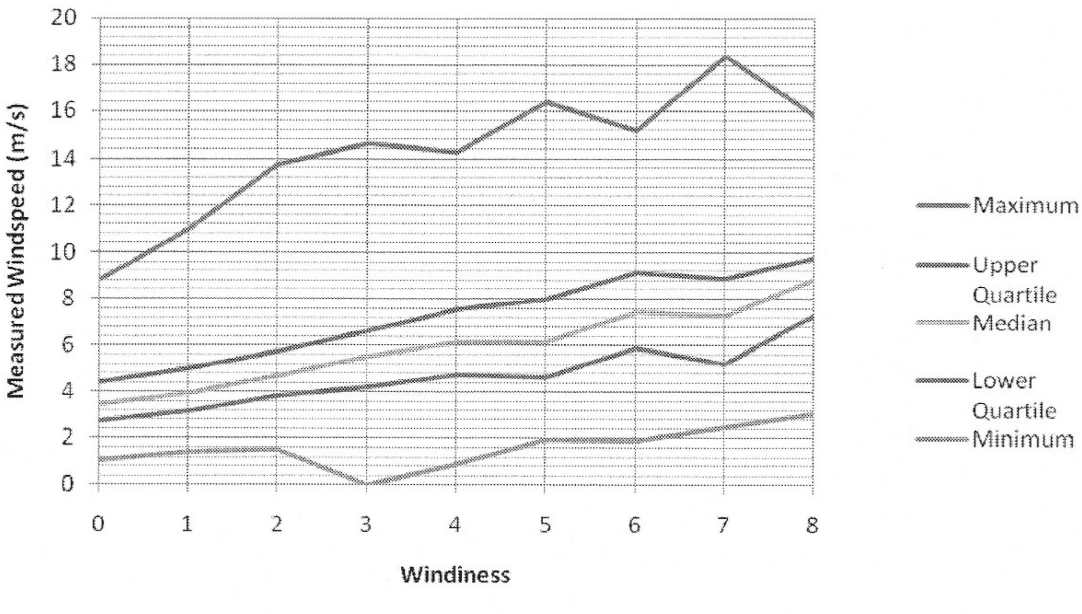

FIGURE 3: Distribution of mean wind speed values at each windiness level.

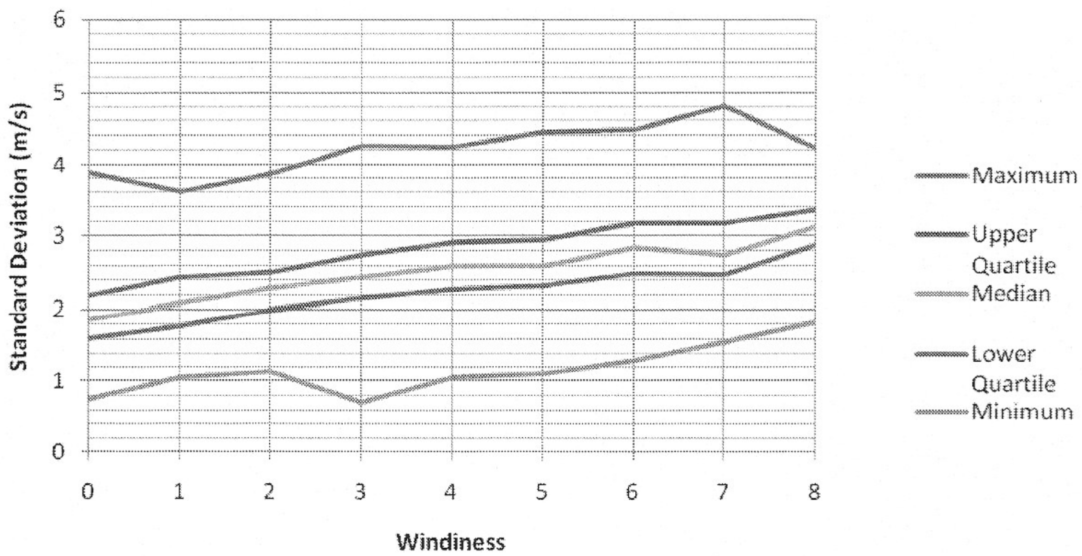

FIGURE 4: Distribution of standard deviation values at each windiness level.

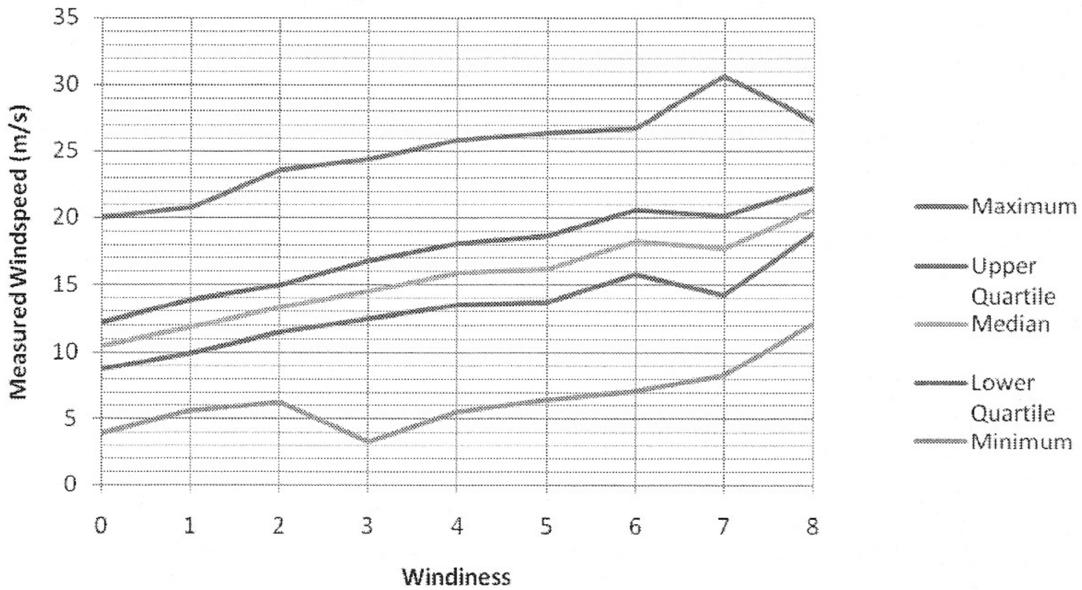

FIGURE 5: Distribution of calculated maximum values at each windiness level.

Considering the calculated max data, for example, on average only 50% of the results lie within ±2.5 m/s of the median figure. The maximum and minimum are typically within ±10 m/s of the median. Compared to the base reading error for wind speed data of ±1 m/s, variation of the erosion windiness measurement is very large. All results are fairly consistent, as each graph depicts a similar yet proportional margin of error. It is apparent that the erosion technique can only be used to obtain an indication of the wind conditions. It is impossible to measure a relevant and accurate wind speed solely through erosion testing.

Identified Wind Flow Characteristics

Where a building is anomalous in a city, such as a tower which is taller than its surroundings, then significant wind effects at ground level can be expected. The range of different flow characteristics can affect the wind flows at street level in different ways. It was anticipated that these might affect the flow visualisations differently. Three specific flow characteristics were identified throughout the data: downwash, open areas, and corner flow. Each had to be clearly defined as indicated below:

- Downwash – Exposed windward building face perpendicular to the wind flow.
- Open Areas – Exposed featureless terrain.
- Corner Flow – Exposed windward corner of a building.

There were around 100 selected points associated with downwash, 100 associated with corner flow and 250 identified as open areas.

The goal was to examine whether the very low levels of correlation between the measured wind speeds and the apparent windiness of a location could be a result of these flow characteristics. It is clear that the erosion test must be measuring a particular component of the wind flow conditions, as well as providing an indication of wind speed. Figure 6 plots these new studies. In summary Figure 6 shows:

1) The trend line associated with corner flows (blue) has a steep gradient. This suggests that where corner flows occur: low erosion levels are associated with low wind speeds, conversely, high wind speeds are associated with high levels of erosion. Therefore corner flows are being measured consistently through both testing procedures.
2) The trend line associated with downwash (red) has a comparatively flat gradient. This shows that in areas of downwash there is no correlation between erosion technique and point speed measurements. Therefore: either a) hot film anemometry underestimates downwashes; or b) bran erosion over exaggerates wind flow characteristic; or c) a combination of both of these effects.
3) The majority of results for open areas (green) lie at the low end of the windiness scale. This fact is not particularly well illustrated in this graph as the trend line is independent of the horizontal data distribution. It does show that higher than average wind speeds are being recorded at all windiness levels. This seems to indicate there is not enough turbulence in the wind flow to cause erosion in areas that record high measured wind speeds.

There are a number of obvious inconsistencies in the way the erosion technique quantifies known flow characteristics. The two causing most concern are areas of downwash and open areas. Vertical wind flow (downwash) tends to over exaggerate the erosion. This is apparently because the bran is more easily disturbed by this vertical wind flow when compared to horizontal wind flow. However, due to the vertical orientation of the hot film anemometer sensor only the horizontal component of the wind is being measured for comparison.

Open areas in which high measured wind speeds are occurring appear to be under eroded. This is potentially due to the lack of turbulence in the wind flow to cause erosion. Recognising this anomaly is important, as the erosion technique could show very little erosion in areas in which unsafe wind speeds occur.

The highlighting of these flow characteristics has not suggested a simple solution. It has suggested there is some level of consistency between wind speeds and windiness levels within each class of aerodynamic flow. But there is not sufficient evidence to be able to improve the correlation to the extent where erosion testing might be argued to be a replacement for wind speed measurement.

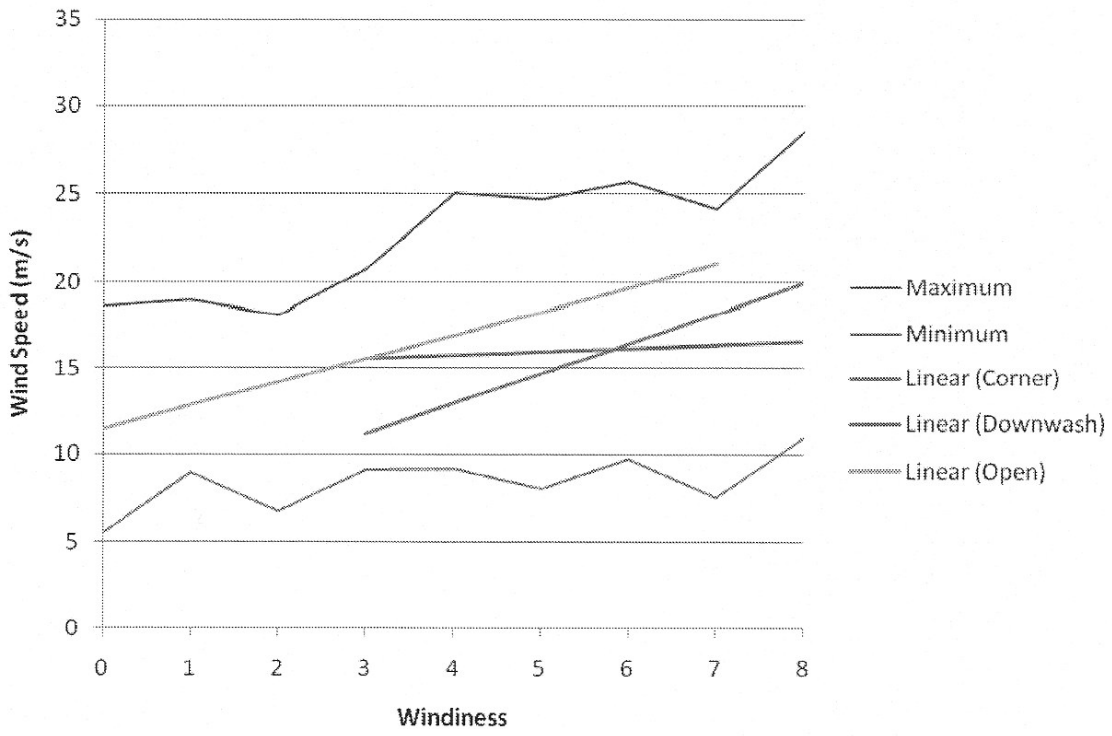

FIGURE 6: Plot depicting the distribution of identified flow characteristics.

Conclusions

The study has shown that it is not possible to determine measured wind speeds solely through conducting bran erosion tests. The correlation between the bran erosion windiness and the hot film wind speed is poor. Generally only 50% of the recorded mean wind speeds at each of the windiness levels derived from flow visualisation lay within a reasonable margin of error.

The analysis has shown that erosion test are indicative of broad flow effects, but not of localised predictions of wind speed. Point wind speed measurements are essential for a wind tunnel study seeking to publish predictions of risk of exceeding comfort or safety standards.
Because wind speed measurements with hot wire/film anemometers have been more rigorously validated against full-scale measurements, it has been assumed that this data is more accurate as well as being more precise.

This analysis has also shown that the erosion technique and the hot film anemometer measurements quantify various known wind flow characteristics differently.

Vertical wind flow (downwash) tends to exaggerate the erosion of the bran. This is apparently because the bran is more easily disturbed by this vertical wind flow when compared to horizontal wind flow.
Open areas in which high measured wind speeds occur are under eroded in the erosion tests. Recognising the effects of different flow features in the erosion tests is very important, as the erosion technique can show very little erosion in areas in which unsafe wind speeds occur.