WIND VELOCITY FIELD AT CAPE MORETON

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INTRODUCTION

Wind velocity fields around complex topographical features are frequently required for calculations in building design, site evaluation for wind energy potential and siting or calibrating meteorological instrumentation. One such AWS anemometer site is on a cliff-top at Cape Moreton, on Moreton Island near Brisbane. The ground-level at the site is at an elevation of approximately 100m. The AWS anemometer is known to generally over-predict near-surface ocean and flat land wind conditions, but the variability with wind speed and direction is unknown. The Bureau of Meteorology-Qld commissioned a wind tunnel study to obtain the "near ground-level wind velocity field" at the Cape Moreton AWS site and surrounding areas. This is accomplished by determining the directional +5m AGL mean (10 min average) and peak wind speed ratios between the Cape Moreton AWS and surrounding areas, to the +5m AGL wind speed over flat land using wind tunnel modeling, for winds approaching from directions around the compass. The combination of these velocity ratios and flow visualisation is used to provide a description of the wind field.

WIND FLOW OVER THE EARTH'S SURFACE

Wind flow influenced by frictional forces near the earth's surface forms an atmospheric boundary layer, which may extend up to a height of more than 1000m. Mean wind speed and turbulence intensity profiles that are dependent on the terrain roughness defined in AS/NZS 1170.2 [1], are based on the logarithmic law as described by the Deaves and Harris [2] model. The terrain roughness, which is represented by the roughness length, z_0 in AS/NZS 1170.2 [1], may also be measured by the surface drag coefficient. Based on empirical relationships, Holmes [3] showed that the roughness length of the ocean varies from about 0.21mm to 1.22mm with the increase of mean wind speed from 10 to 20 m/s. Using full scale data, Melbourne and Blackman [4] found z_0 values ranging from 0.002m to 0.2m for mean wind speed from 20 to 30 m/s, as higher wind speeds create larger waves resulting in increased surface drag over the ocean.

Ground-level, mean and gust wind speeds can be significantly affected by the local topography, such as cliffs, hills, ravines etc. For example, as the wind approaches a shallow hill, its speed reduces slightly as it encounters the start of the upward slope, and then increases as it flows up the crest. The maximum speedup occurs at or near the crest, followed by a gradual reduction downstream to a value close to that well upwind of the hill. For steeper hills, flow separation can occur immediately downwind of the crest or further downstream, along with an effective "stagnation" region on the steep upwind slope. Research carried out to study flow fields over simple 2D and 3D shapes have produced topographical factors for mean and gust wind speeds, that are incorporated in standards [1]. However, estimation of topographical factors for use on more complex topographical features is difficult, and often requires a wind tunnel model study.

WIND TUNNEL TESTS

A wind tunnel study was carried out in the 2.5m × 2.0m × 22m long Boundary Layer Wind Tunnel, in the School of Engineering at James Cook University in Townsville. The approach boundary layer wind flow was modeled at a length scale of 1/1000, using a fence at the upstream end followed by a layer of carpet on the wind tunnel floor. This arrangement satisfactorily simulated the mean velocity and turbulent intensity profiles representative of a terrain category 2-3 approach atmospheric boundary layer flow (as per AS/NZS 1170.2[1]) over open terrain and rough open water surfaces under neutrally stable approach winds. A topographic wind tunnel model of the Cape Moreton AWS site and its surrounds were constructed at a length scale of 1/1000, and installed on the turntable as shown in Figure 1.

Omni-directional wind speed sensors were installed at the AWS position and at another thirty-three surrounding locations, on the topographic model as shown in Figure 2. The sensors were located on a radial grid and identified by its distance from the center of the model (i.e. AWS position) pre-fixed with the direction, such that for example, E500 refers to the location 500m from the AWS in the Easterly (E) direction. Local wind flow patterns were determined using smoke flow visualisation. Additionally, mean wind velocity profiles were measured at the AWS position at approximately +10m, +20m, +50m and +100m AGL, for Northerly, Easterly, Southerly and Westerly approach winds.

Fluctuating wind speeds (i.e. +5m AGL wind speed vs time) were measured at each sensor location, for approach winds around the compass at intervals of 22.5°. The Northerly, Easterly, Southerly and Westerly approach wind directions are defined as 0°, 90°, 180° and 270° respectively. The mean and peak wind speed at each sensor location were recorded in terms of a ratio to the mean gradient wind speed at an elevation of 500m, in a terrain category 2-3 approach, over a flat surface. This data was used to compute the +5m AGL wind speed ratios, at each location, for each approach wind direction.

DATA ANALYSIS AND RESULTS

Three velocity records of 12 sec duration (which corresponds to three, 10 min full-scale records, based on similarity scaling) were collected at each sensor location. Statistical analyses were carried out on the fluctuating wind velocity at each sensor location *i*, $V_i(t)$ to give the mean velocity averaged over 10 mins $\overline{V_i}$, and the peak 3sec gust velocity at *i*, $\hat{V}_i$. These values were recorded in coefficient form by dividing by the mean approach gradient velocity at the reference "gradient" height of 500mm (i.e. 500m in full-scale), as follows: +5m AGL mean velocity coefficient at $i = \overline{V_i}/V_g$, and +5m AGL peak velocity coefficient ratio at *i* $= \hat{V}_i/V_g$, where V_g is the mean approach velocity at "gradient" height of 500 mm (i.e. 500m in full-scale). The +5m AGL mean and peak velocity coefficients on flat land were approximately 0.45 and 0.8 respectively, closely matching values for terrain category 2 in AS 1170.2 [1] of 0.49 and 0.84 respectively.

The +5m AGL mean and peak wind speed ratios at the Cape Moreton AWS site and four other locations N100, E100, S100, W100, with the +5m AGL surface winds over flat land with approach wind direction are presented in Figures 3 to 7 respectively. These Figures show that, mean and peak wind speeds at the AWS position, exceed the +5m AGL on flat land by more than 50% and 30% respectively for winds from the NW-N-E-SE sector, and by more than 20% and 10% respectively for approach winds from the other directions. The variation of mean wind speed with elevation at the AWS site for Northerly, Easterly, Southerly and Westerly approach winds are given in Figure 8. Figure 8 shows the effect of shielding from the lighthouse for Southerly winds, and increasing mean wind speed with elevation above ground. Combined with smoke flow visualisation patterns and +5 AGL velocity ratios at the other sensor locations, the wind field summarised as:

- *NW-N-NE approach winds*: Marginal slowdown at Northern approaches to the cape. Speedup over the AWS site and ~100m radius. Increased turbulence / wake to the South of the AWS. Normal speeds on the ocean to the east outside the influence of the cape.
- *NE-E-SE approach winds*: Progressive slowdown to stagnation at the base of the cliff. Significant increase in wind speed over the steep upwind slope on the Eastern approach to the AWS. Significant speedup over the AWS site. Normal speeds downstream of the AWS.
- *SE-S-SW approach winds*: Some slowdown and increased turbulence at the Southern part of the cliff face. Winds directed along the cliff face line at ocean level. Increased wind speeds over the cliff face and the AWS site.
- *SW-W-NW approach winds*: Normal wind speeds over approach topography. Increase in wind speed over the AWS site. Flow separation, slowdown and increased turbulence / wake over the Eastern steep downwind cliff slope. Normal wind speeds far downstream on the ocean.

CONCLUSIONS

A topographic wind tunnel model study was carried out at a length scale of 1:1000 on an area containing the Cape Moreton AWS site and its surrounds. Wind velocities were measured at the AWS site and other locations around the AWS site, and presented in terms of ratios of +5m, mean and peak AGL wind speeds to the +5m, mean and peak AGL wind speed over flat land, at sea-level.

The wind tunnel study showed that the wind field at the AWS site and its proximity to a distance of about 200m is greatly influenced by the surrounding topography. Increased near ground level mean and peak wind speeds compared with the mean and peak wind speeds over flat land were measured on the upwind slopes and the crest of the cape, whilst decreased mean and peak wind speeds were measured on steep downwind slopes and at the upwind base of the steep cliff.

REFERENCES

1. AS/NZS 1170.2 Structural design actions – Part 2: Wind actions, (2002), supercedes AS1170.2 (1989)
2. Deaves, D. M. and Harris, R. I., "A mathematical model of the structure of strong winds", CIRAA Report 76, (1978)
3. Holmes, John D., "Wind loading of structures" Spon Press, (2001)
4. Melbourne, W.H. and Blackman, D.R., Wind turbulence over seas in tropical cyclones. Proc. Intl. Conf. Coastal Engin., ASCE, 370-383 (1982)

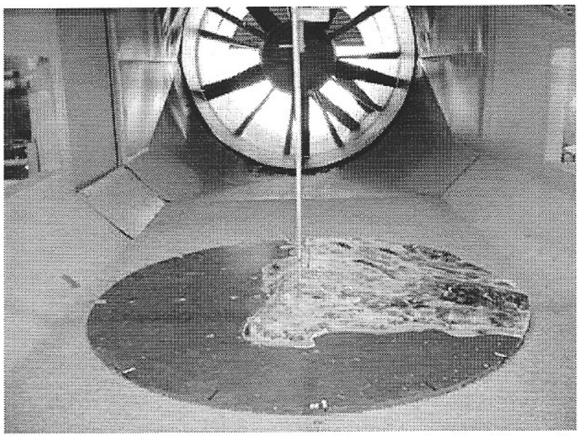

Figure 1. 1:1000 scale topographic model of Cape Moreton in the Boundary Layer Wind Tunnel

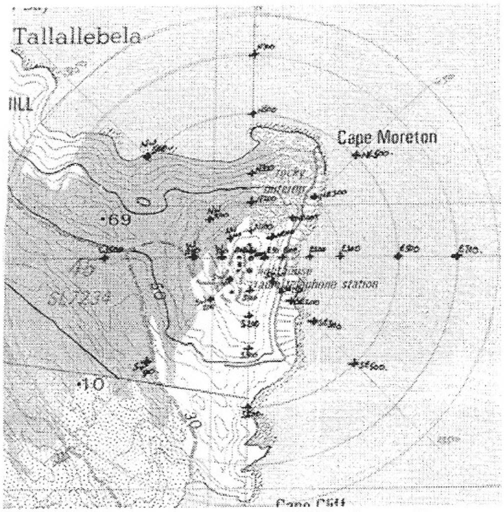

Figure 2. Map of elevation contours of Cape Moreton AWS site and surrounds, showing sensor locations

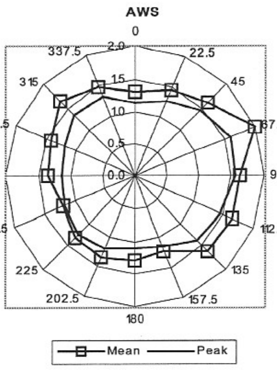

Figure 3. Ratios of mean and peak +5m AGL wind speed at the AWS to mean and peak +5m on flat land

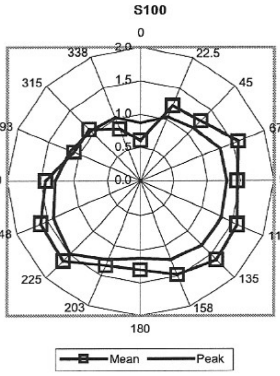

Figure 6. Ratios of mean and peak +5m AGL wind speed at S100 to mean and peak +5m on flat land

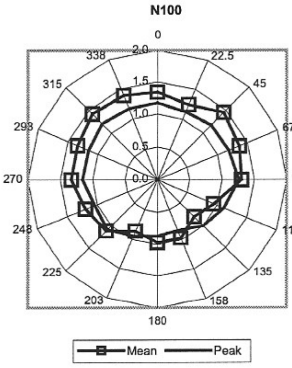

Figure 4. Ratios of mean and peak +5m AGL wind speed at N100 to mean and peak +5m on flat land

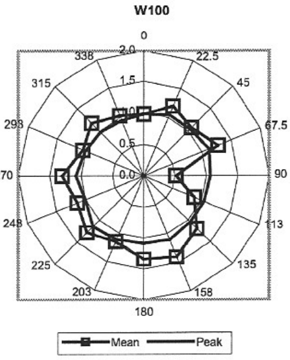

Figure 7. Ratios of mean and peak +5m AGL wind speed at W100 to mean and peak +5m on flat land

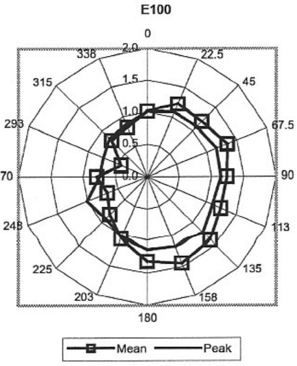

Figure 5. Ratios of mean and peak +5m AGL wind speed at E100 to mean and peak +5m on flat land

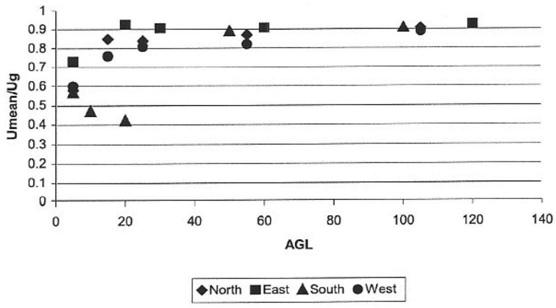

Figure 8. Ratios of mean AGL wind speed to mean 500m gradient wind speed at the AWS, for winds approaching from N, E, S and W