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Some Effects of an Isolated Hill on Wind Velocities near Ground Level

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SUMMARY This paper describes an initial series of measurements in a project to investigate the modification of strong wind velocities near ground level by an isolated hill. Most of the results presented were obtained from a 1/2000 scale model tested in a boundary layer wind tunnel. However, some full scale data measured using a number of anemometers designed to record the maximum horizontal gust velocity, have been obtained, and compared with the wind tunnel results for the corresponding wind direction.

1 INTRODUCTION

That hills and other natural topographical features have strong effects on wind velocities near ground level is well known and readily experienced by casual observers. Reports on building damage resulting from the recent occurrences of severe tropical cyclones in Northern Australia have also indicated strong topographical influences in damage patterns.

Quantitative estimates of amplification or attenuation of wind velocities by natural topography have proved difficult for several reasons, however. Theoretical solutions for turbulent boundary layer profiles over level surfaces are difficult due to the problem of specifying satisfactory turbulence closure relations. The atmospheric boundary layer has the additional complication of Coriolis forces induced by the earth's rotation, and, in the case of tropical cyclones, of centrifugal inertia effects due to the curved flow trajectories resulting from the vortex nature of the storm. The effect of a varying surface boundary introduces additional complexity, and the occurrence of separated flow regions and wakes with steep terrain contours has made complete theoretical solutions impossible to date.

Full scale measurements are an obvious requirement, and these are being carried out to an increasing degree. However, there are great difficulties in providing data of a sufficient quantity and quality without very large expenditure in equipment and personnel. The advent of the boundary layer wind tunnel with greatly improved modelling of the atmospheric boundary layer flow conditions has introduced the possibility of reliable laboratory estimates of topographical effects on wind velocities at a relatively low cost. However, continuing wind tunnel/full scale comparisons are essential to establish confidence in the laboratory procedures and the importance of scaling effects.

The present paper describes some results in a study to establish the effect of an isolated three-dimensional hill on mean and turbulent flow velocities at a height of 10 m or equivalent. The study includes both full-scale and wind tunnel measurements, although the present paper is mainly concerned with a series of wind tunnel tests carried out with a 1/2000 scale model. Some comparison is made with some initial full scale results, however.

2 DESCRIPTION OF FULL-SCALE SITE

The site chosen for the study is a prominent isolated topographic feature within the city of Townsville known as Castle Hill (Fig. 1).

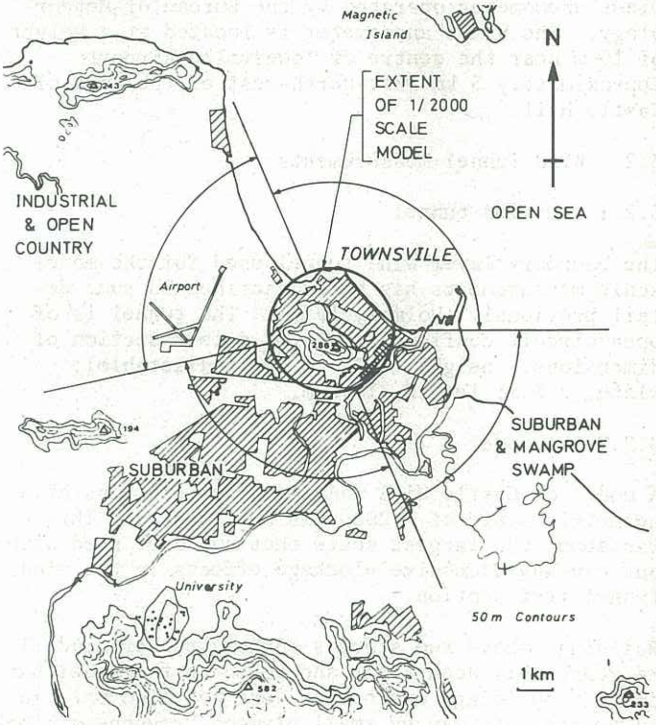

Figure 1 Site map

Castle Hill is a steep sided hill rising to a height of 286 m from the flat flood plain of the Ross River on which Townsville is located. The main hill has a roughly rectangular base, of the order of 2½ km long and 1½ km wide, running N.W.-S.E. parallel to the coast, which is approximately 1 km to the north east.

Most of the hill is a nature reserve lightly covered with eucalypt trees and scrub. Buildings, mostly houses, are confined to the lower edges below the 50 m contour.

In its immediate vicinity, the hill is exposed to the sea on the north east, flat open country, swamp and salt pans to the north west and south east, and suburban residential development to the south west.

There is no other topographical feature of any significance closer than 5 km from Castle Hill.

The prevailing winds come from the sector between north east and south east. The most severe winds from tropical cyclones can be expected to come from the eastern semi circle between north and south, the actual directions being dependent on the track and size of the tropical cyclone.

3 MEASUREMENT PROCEDURES

3.1 Full Scale Measurements

For the present project, in order to provide wind measuring devices at sufficient locations cheaply, a simplified instrument known as the Marshall "maxometer" was developed. This instrument records wind gusts in magnitude and direction. It is described in a paper by Walker and Marshall (1980). The Marshall maxometers were mounted on tripod supported masts at a height of 10 m above ground. For the study a total of 20 of the instruments have been erected at various locations on and adjacent to Castle Hill, with 11 being placed on Castle Hill itself.

In addition to the Marshall maxometer records, continuous chart recordings were obtained from a Dines anemometer operated by the Bureau of Meteorology. The Dines anemometer is located at a height of 10 m near the centre of Townsville Airport approximately 3 km west-north-west of the edge of Castle Hill.

3.2 Wind Tunnel Measurements

3.2.1 The wind tunnel

The boundary layer wind tunnel used for the model scale measurements has been described in some detail previously (Holmes, 1977). The tunnel is of open circuit configuration with a test section of dimensions: height, 1.9 - 2.1 m (adjustable); width, 2.5 m; length, 13.5 m.

3.2.2 The model

A model of Castle Hill and immediate environs at a geometric scale of 1/2000 was constructed. This was about the largest scale that could be used without causing excessive blockage effects in the wind tunnel test section.

Buildings above two storeys in height, were modelled reasonably accurately and added to the model but smaller buildings and houses were modelled only in an approximate way by small plywood "roughness blocks".

Figure 1 shows the extent of the model and Figure 2 shows the model in the wind tunnel.

Figure 2 1/2000 Scale model in wind tunnel

3.2.3 Instrumentation

Three types of probe were used in the wind tunnel study. A two-dimensional "Cobra" yaw meter and a T.S.I. linearized hot film anemometer were used to measure flow characteristics, and a pitot-static tube was used for calibration purposes. The probes were mounted on a horizontal radial arm supported from the roof of the tunnel (Figure 2).

Mean flow directions at each site on the model, measured by means of the "Cobra" probe, were used to orientate the hot film probe in a second series of tests. The wind tunnel measurements were taken at a height above local ground of 5 mm (≡ 10 m in full scale).

The outputs from the T.S.I. linearized anemometers were sampled by an A/D converter associated with a PDP/8E mini-computer, and drifts of zero flow readings and sensitivities were corrected using the latter. Velocity signals were sampled at 1800 Hz for 20 seconds.

4 WIND TUNNEL UPWIND FLOW PROPERTIES

The only fetch conditions that have been reproduced in the wind tunnel, at this stage, are the low roughness length conditions appropriate to the open types of terrain characteristic of the prevailing fetch. Figure 3 shows mean velocity and turbulence intensity profiles for the wind tunnel, at the end of a fetch consisting of about 11 m of particle board laid on the floor of the tunnel. The profiles in the surface layer (up to about 100 m height in full scale), are fitted quite well with standard empirical profiles based on the logarithmic law, with a roughness length of about 7 mm in full scale. This is an appropriate value for open sea terrain (E.S.D.U. 1974). The boundary layer height is about 600 m in full scale - about twice the height of the hill.

The spectral density of the longitudinal velocity fluctuations (not shown) was in reasonable agreement with standard empirical forms (e.g. E.S.D.U. (1974) with a length scale appropriate to the geometric scaling ratio of 1/2000.

5 FLOW ON THE HILL

5.1 General Characteristics

Wind tunnel mean flow directions and amplification factors are presented in the form of vectors for the prevailing easterly wind direction in Figure 4. The values of the mean flow amplification factor and the turbulence intensity for each site, corresponding to the full scale maxometer locations, are shown alongside the corresponding vector.

5.2 Amplification Factors

An amplification factor is defined as the ratio of a velocity at the site to that at a reference position upwind of the model (both at 5 mm height). The amplification factors for the mean wind velocity, the maximum longitudinal velocity and longitudinal root-mean-square (r.m.s.) fluctuating velocity are plotted in the form of polar plots for five locations in Figure 5. The directions indicated on the polar plots are those for the reference mean wind velocity and not for the distorted velocity vector on the hill.

A number of general characteristics can be deduced from these and similar plots for the other locations:

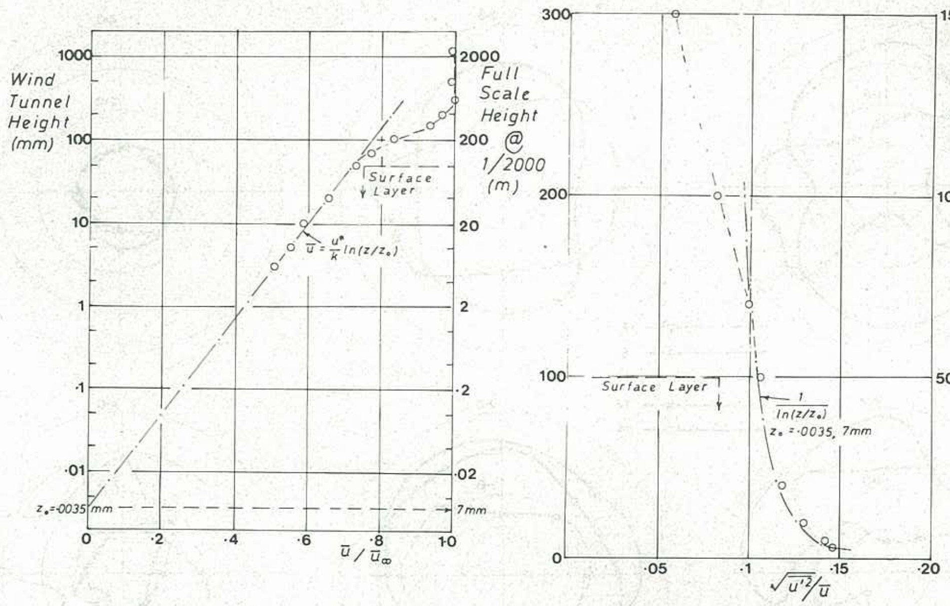

Figure 3 Mean velocity and turbulence intensity profiles

(i) The mean wind amplification factor varies over a wide range both from point to point and for different wind directions for a particular point. The lowest and highest values were both measured for position 14: 0.29 for a south-east wind and 2.15 for a south-west wind direction, respectively.

(ii) The amplification factor for the r.m.s. fluctuating velocity shows very little relationship with the mean velocity amplification factor. The upwind turbulence is essentially smaller in scale than the hill dimensions, and considerable distortion occurs as it is transported past by the mean wind. In addition, eddy shedding may occur resulting in additional fluctuations in separated flow and wake regions. The r.m.s. amplification factor is generally greater than unity, but usually does not exceed 2. The exception to the latter is position 11, which is near the summit of the hill for which values greater than 2 occurred for several wind directions, with a value of 3.4 recorded for the east-north-east wind direction.

(iii) The peak gust amplification factor is the most significant when considering wind loads on houses and other small structures. It may be regarded as a combination of the mean wind and r.m.s. amplification factors. The effect of combining is to smooth out the variations with wind direction. Typically, the amplification factor for the peak gust lies between 1 and 1.5: the lowest recorded was 0.73 and the highest was 1.68.

In the following some attempt has been made to isolate effects on a generalised basis, although the complex three-dimensional nature of the flow makes this difficult:

(a) Base of windward slopes - These locations generally show attenuation of the mean wind velocity with little change to the r.m.s. velocity. An example is position 12 for southerly winds.

(b) Higher up on windward slopes and sides of hill - In these cases, the mean wind velocity is usually amplified but the r.m.s. amplification factor again remains fairly close to unity. An example is position 5 for southerly winds.

(c) Wake or separated flow regions - In these regions, the mean wind is usually attenuated but the fluctuating component is amplified. This is the case for position 5 for westerly winds.

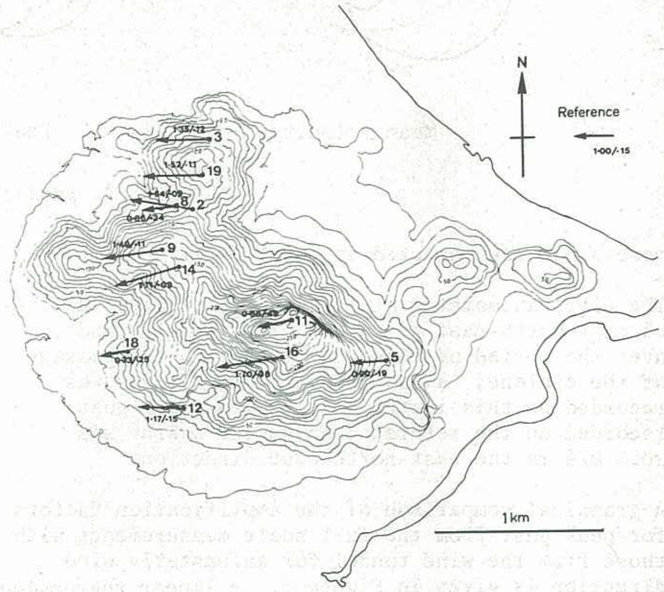

Figure 4 Mean velocity vectors (wind tunnel)

Position 2 is on a "saddle" between the main hill and the Yarrawonga outcrop. For east and west winds no shielding by the adjacent high ground occurs and a strong amplification of the mean wind results; the r.m.s. amplification factor is close to unity. The characteristics are thus similar to case (b) for these directions, and to case (c) for the north and south winds.

Position 11 is in a locally depressed area surrounded by three peaks, one of which is the summit of the hill. Eddy shedding from these peaks probably causes the very high r.m.s. values for almost all wind directions. The mean wind amplification factor varies widely, depending on whether the position is in the lee of one of the peaks or not.

5.3 Full Scale/Model Comparison

At this stage, only one occasion has occurred in which the wind velocity has been sufficiently high and constant in direction, to enable useful full scale data to be obtained. This was at the time tropical cyclone "Peter" crossed Cape York Peninsular between the Gulf of Carpentaria and the Coral Sea in mid-January 1979. At this time ten maxo-

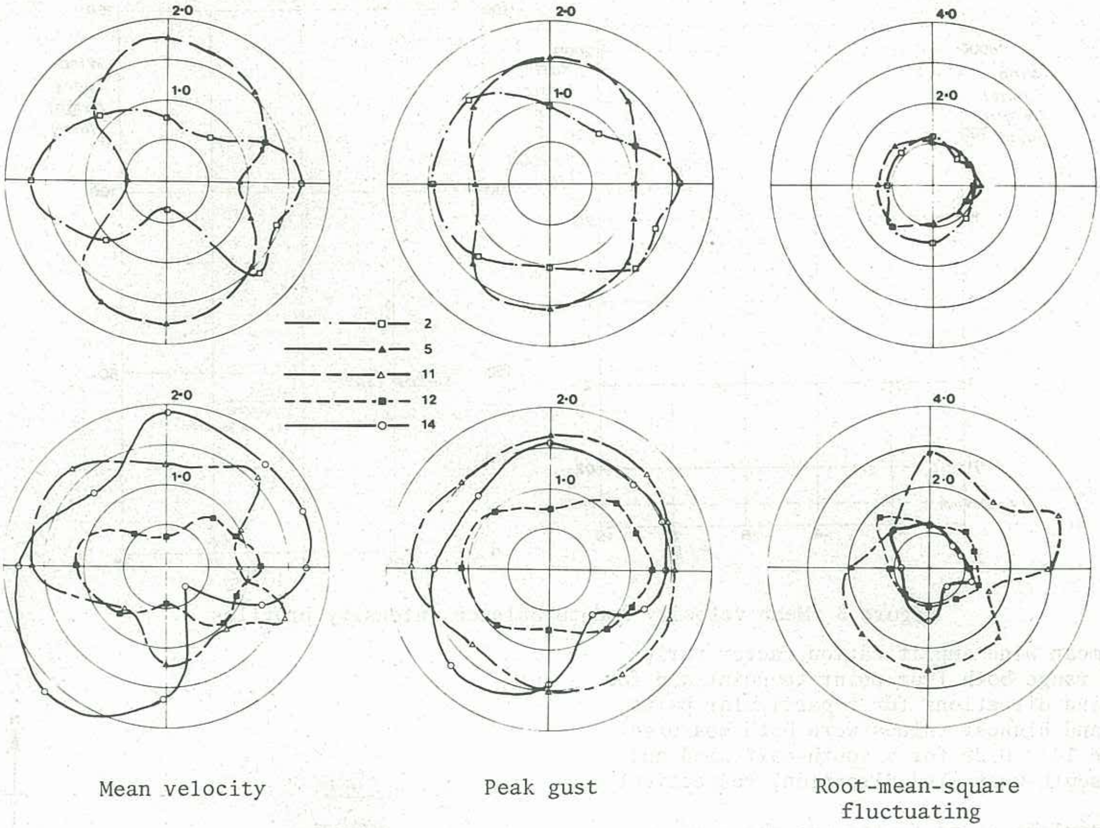

Figure 5 Amplification Factors

meters had been erected on Castle Hill.

The Dines anemometer at the airport nearby, indicated east-north-east to east-south-easterly winds over the period of three days covering the passage of the cyclone; a maximum gust of 22.1 m/s was recorded on this instrument. The maximum gust recorded on the reference maxometer nearby was 20.3 m/s in the east-north-east direction.

A graphical comparison of the amplification factors for peak gust from the full scale measurements with those from the wind tunnel for an easterly wind direction is given in Figure 6. A linear regression line of the field data on the model values have been estimated and drawn on Figure 6. The intercept is seen to be close to zero and the slope near unity, with a correlation coefficient of 0.78.

6 CONCLUSIONS

The main conclusions from this initial study of wind velocities near ground level on an isolated hill are as follows:

(i) Considerable amplification of mean and fluctuation velocities was observed in the wind tunnel tests; attenuation of the mean velocity occurred in wake regions. The maximum observed values of mean wind and r.m.s. fluctuating velocity amplification factors were 2.15 and 3.4 respectively.
(ii) The amplification factors for peak gust velocities were less dependent on wind direction than were those for the mean and r.m.s. velocities. Typically values of between 1 and 1.5 occurred, with maximum values near 1.7.
(iii) Significant direction changes were induced in the mean velocity vectors in the wind tunnel tests.
(iv) Preliminary comparison of wind tunnel data with full scale measurements of peak gust amplification factor for an easterly wind direction showed encouraging agreement.

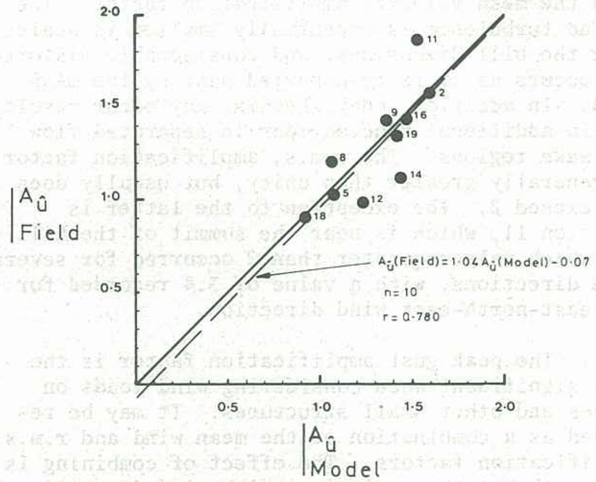

Figure 6 Full Scale/Wind tunnel comparison of peak gust amplification factors.

7 ACKNOWLEDGEMENTS

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