Performance Of Windtech's Slatted Roof Blockage Tolerant Boundary Layer Wind Tunnel in 3D Flow

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ABSTRACT: The paper discusses the outcomes of converting Windtech's Boundary Layer Wind Tunnel to a Blockage Tolerant Boundary Layer Wind Tunnel. The resulting changes to the wind tunnel design were found to be effective in reducing blockage effects that become apparent when examining the surface pressure coefficients on large three dimensional models.

KEYWORDS: blockage, tolerant, wind tunnel, pressure coefficients, three-dimensional

1 INTRODUCTION

The use of a transversely slatted roof over the test section was recently incorporated into the upgrade of Windtech's boundary layer wind tunnel to minimise the effects of blockage. The design that was chosen for this upgrade is based on the parametric study by Glanville and Kwok [1]. This design has been shown to be effective on two-dimensional models. This paper presents a study of the performance of this design in the case of three-dimensional flow. Surface pressures on a cube were examined and compared with full scale results, obtained from the Silsoe Research Institute [2], such that a limit to the size of the blockage in the wind tunnel could be determined, for both blockage tolerant and non-blockage tolerant cases.

2 REVIEW

There have been previous studies into the use of slatted wind tunnel surfaces for reducing blockage effects. In Parkinson and Cook [3], the proven methodology for providing blockage tolerance to one- and two-dimensional bluff bodies was incorporated into the design of the BRE Blockage Tolerant Boundary Layer wind tunnel. The use of a slatted wall/ slatted roof blockage tolerant wind tunnel was examined, leading to some discouraging results. On examination of Glanville and Kwok's work it can be seen that these discouraging results are due to a small slatted wall length (L_s). From [1], the optimum L_s to tunnel height ratio is 2.5 (see Figure 1), whilst this ratio was only 1.3 in Parkinson and Cooks setup.

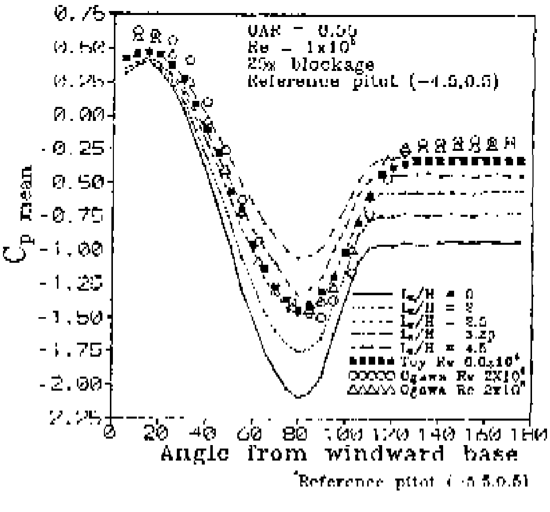


Figure 1: Results from [1], illustrating that L_s/H of 2.5 provides the optimum correlation with blockage free results (Toy, Ogawa)

3 EXPERIMENTAL SETUP

Windtech's boundary layer wind tunnel is an open-end wind tunnel, with a section width of 2.6m, section height of 2.0m and a fetch length of 14m. The design used to provide blockage tolerance, as stated previously, is that used by Glanville and Kwok [1]. The key parameters in this design are the Open Air Ratio (OAR), the slatted wall length L_s and the plenum depth. The same type of aerofoil used in [1] was also used (NACA0015). A slatted wall length of 5m was chosen, giving the optimum L_s /H of 2.5, and the OAR was 0.55. The plenum depth was 0.64m. A sample photograph of one of the test models in the wind tunnel is shown in Figure 2. The layout of the wind tunnel is shown in Figure 3.

Figure 2: The 4.4% blockage cube in Windtech's blockage tolerant boundary layer wind tunnel, at incidence angle 45 degrees.

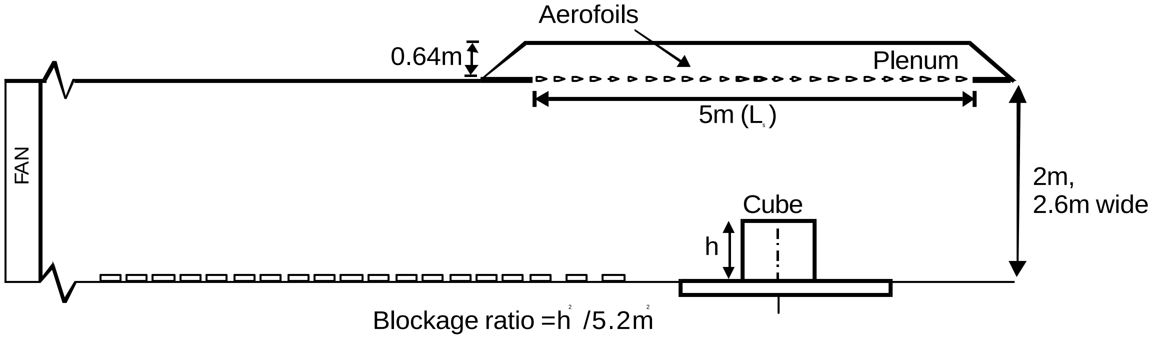


Figure 3. Wind Tunnel Setup.

Four models of cubes of various sizes were built for testing in the wind tunnel. These were scale models of a 6m cube, which was field tested at the Silsoe Research Institute. The four cube sizes are 240mm, 480mm, 720mm and 960mm.

Each of the models was fitted with 64 pressure taps (see layout in Figure 4). The taps 1 to 16 correspond to pressure taps on the Silsoe building, whilst taps 17 to 64 were used to monitor wall and roof pressures in more detail.

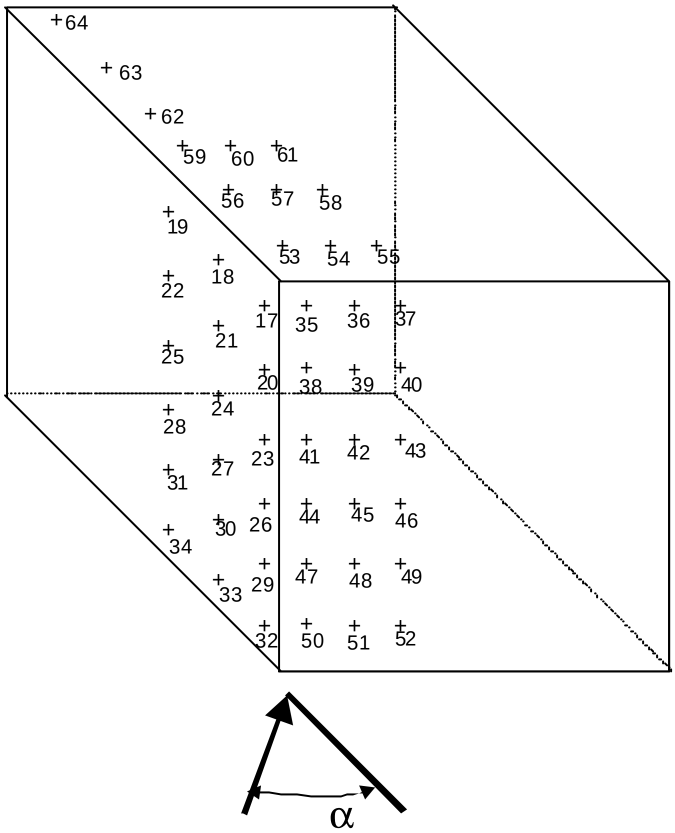


Figure 4. Layout of Pressure Taps.

Before testing both blockage tolerant and non-blockage tolerant situations, the velocity and turbulence profiles for each test were needed. Velocity and turbulence profile data from the Silsoe Research Institute and Terrain Category 2 (AS1170.2-1989) was used to match these profiles, using the augmented technique with spires and trip boards. It was noted that the Silsoe site was situated in a Terrain Category 2 wind environment. For each scale an appropriate velocity and turbulence profile was used, (Figure 5).

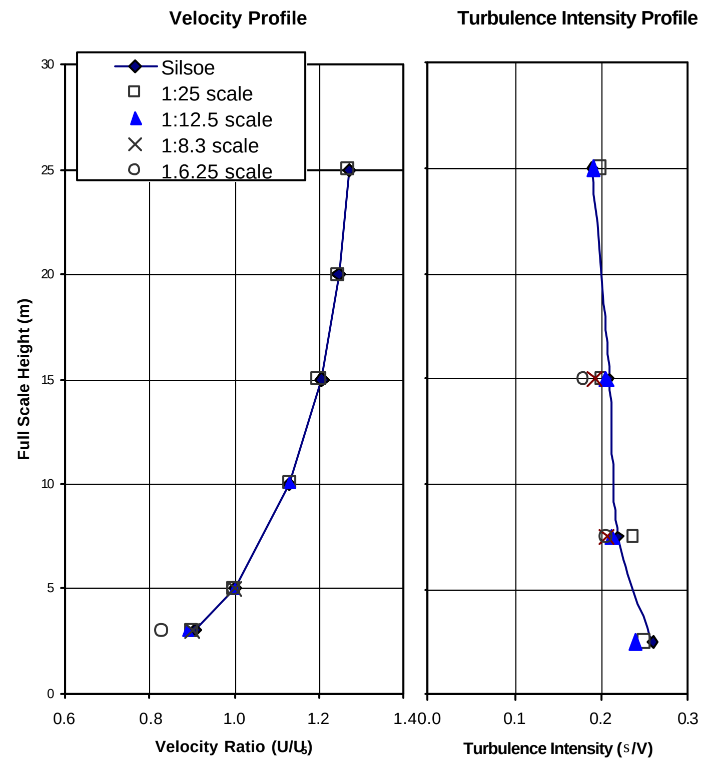


Figure 5: Velocity and Turbulence Profiles.

Along with matching these profiles, Reynolds number was held approximately constant during each test by selecting appropriate wind speeds for each test. The geometric data for each cube is shown in Table 1.

Table 1: Setup data for the various cube models

Cube	Size(mm)	Scale	Blockage at 0^o	Blockage at 45^o	Test Velocity (m/s)	Reynolds number
1	240	1:25.00	1.1%	1.55%	18.00m/s	$2.9x10^5$
2	480	1:12.50	4.4%	6.22%	9.00m/s	$2.9x10^5$
3	720	1:8.33	10.0%	14.14%	5.94m/s	$2.9x10^5$
4	960	1:6.25	17.7%	25.03%	4.50m/s	$2.9x10^5$

The results were obtained using a Type J48 Scanivalve pressure scanning switch, with the results obtained in coefficient form, referenced to building height. Each model underwent four tests, testing both blockage and non-blockage tolerant cases, along with two incidence angles, 0 degrees and 45 degrees. The non-blockage tolerant tests were conducted by sealing the plenum chamber, returning the wind tunnel to its original non-blockage tolerant configuration.

4 RESULTS

The experimental pressure coefficient data with respect to roof height was derived from the test results. This data has been compared to the available full-scale data, for pressures along the spine of the cube (see tap locations 1 to 16), obtained from Silsoe. Figures 6a and 6b show a comparison of the coefficient data for taps 1 to 16 which can be directly related to the Silsoe data. Reynolds numbers have been maintained at 2.9×10^5 and are sufficiently high to allow direct comparison to the full-scale results. The data has also been presented in a series of contour plots using the Surfer 32 contour plotting program, (see Figures 7a to 9b), which was used to present contour plots for each face of the cube. For the latter test the results for the 1.1% NBT case were adopted as a benchmark against which the other results can be compared.

4.1 Windward Wall Pressures

From Figures 6a and 6b it is apparent that the 17.7% NBT cube produces the poorest results, for both incidence angles, with the differences between this data and the field data larger at $\alpha = 45$ degrees, possibly due to the increase in the effective blockage. However, the blockage tolerant results for this cube are closer to the field data, especially when $\alpha = 45$ degrees. The contour plots for this cube, (see Figures 7a and 7b), indicate that a blockage of 17.7% in the wind tunnel will lead to substantial errors in the results, whether the tunnel is BT or NBT. That is not to say that the modifications are not working. The contour plots clearly show that the BT results for this cube are closer to the benchmark data, especially at $\alpha = 45$ degrees.

The contour plots for the other cubes show that for blockages of up to 10%, (or 14.14% at?$\alpha = 45$ degrees), blockage effects are less noticeable. It is only on inspection of Figures 6a and 6b that the poorer performance of the NBT cubes can be seen. One encouraging result from the windward wall pressure data is the performance of the 10% blockage cube at $\alpha = 45$ degrees (14.14% effective blockage). These results are much closer to the field data than the corresponding NBT results. This is not seen in the contour diagram for this cube, due to a low-pressure gradient across this surface.

As expected the BT and NBT results for the lower blockage cubes are very similar up to 6.22% blockage case. The BT setup is effective in offsetting the effect of blockage beyond this level to the 14.14% blockage case.

4.2 Side and Leeward Wall Pressures

Figures 8a and 8b show the contour plots for these regions. From Figure 8a it can be seen that blockages of up to 14.14%, whether in a BT or NBT situation, can be tested without any significant effect of blockage. However, it is apparent that blockages of 17.7% and greater will be effected by blockage errors if tested in an NBT situation, as clearly shown in Figure 8a. Here the NBT case presented pressures up to 70% larger than the 17.7% BT case, or the benchmark 1.1% NBT data. It is evident here that the wind tunnel walls are the cause of these errors. As the walls are a closed boundary the air between the model and the boundary is funneled, causing larger negative pressures on these surfaces.

For $\alpha = 45$ degrees the results illustrate this problem again, with the 17.7% BT case performing much better than the NBT case but with blockage errors in the NBT case still significant.

Pressure taps 12 to 16 monitor the Leeward wall pressures. From figures 6a and 6b it is clear that in the regions of separation that blockage errors become more apparent. However the results show that blockages of up to 14.14% can be tested in a BT situation without the errors associated with blockage affecting the results significantly.

4.3 Roof Pressures

Figures 9a and 9b show the contour plots for the roof pressures. Pressure taps 6 to 11 (see Figures 6a and 6b) are also used to measure the pressure on the roof. As separation begins on this surface, (pressure tap 6), the largest errors in the large blockage (NBT) cases are produced. As separation continues we find that the blockage errors in the BT cases are dramatically reduced, in comparison with NBT cases. For the α = 0 degrees test, blockage errors are significantly reduced for the 17.7% cube with the use of the blockage tolerant tunnel, with the BT case being almost identical to the benchmark results. For blockages of 10% in a non-blockage tolerant case separation has increased along the roof significantly, unlike the BT case which, like the 17.7% case, is almost identical to the benchmark results.

For the α = 45 degrees, NBT case the results for the largest blockage (17.7%, 25.03% effective blockage) are significantly different to the 1.1% NBT results. These increased negative pressure areas have been significantly reduced in the BT case, so much that these results are better than the 14.14% NBT results. For blockages of less 6.22% blockages errors are negligible for both the NBT and BT cases.

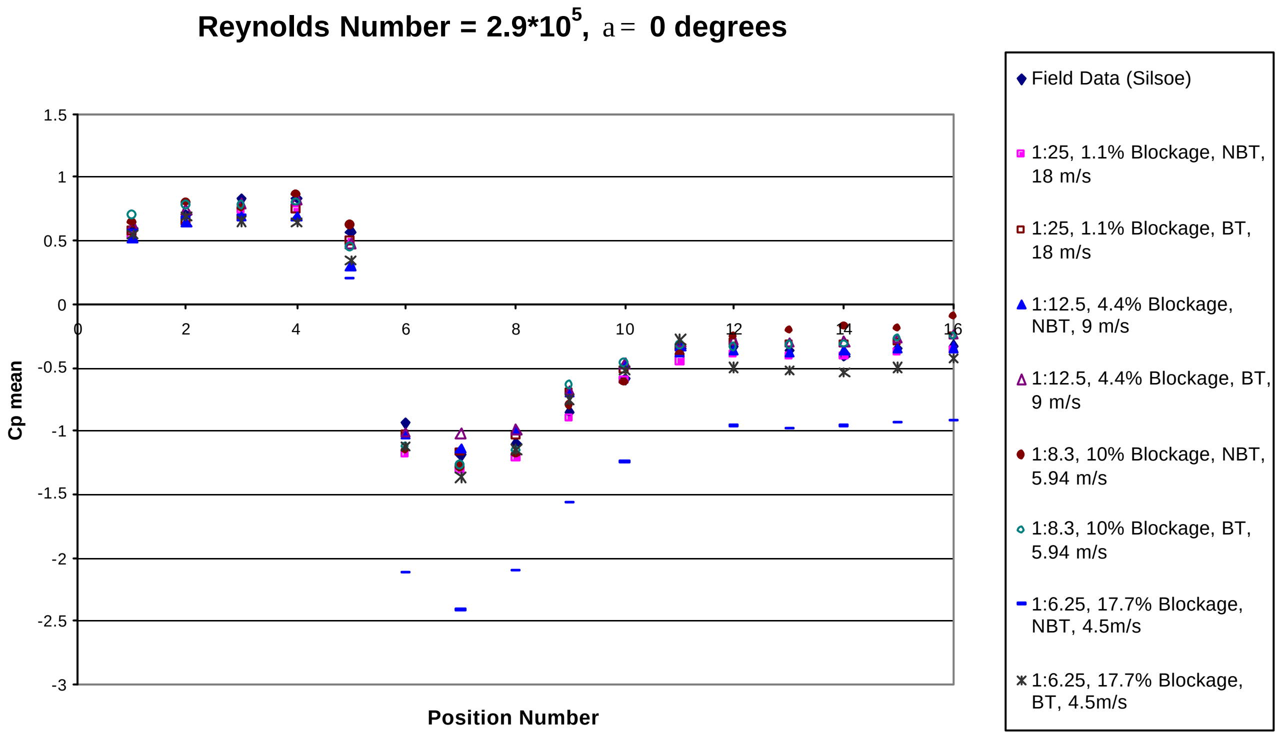


Figure 6a: Mean Pressure Coefficient vs Tap Location, α = 0 degrees

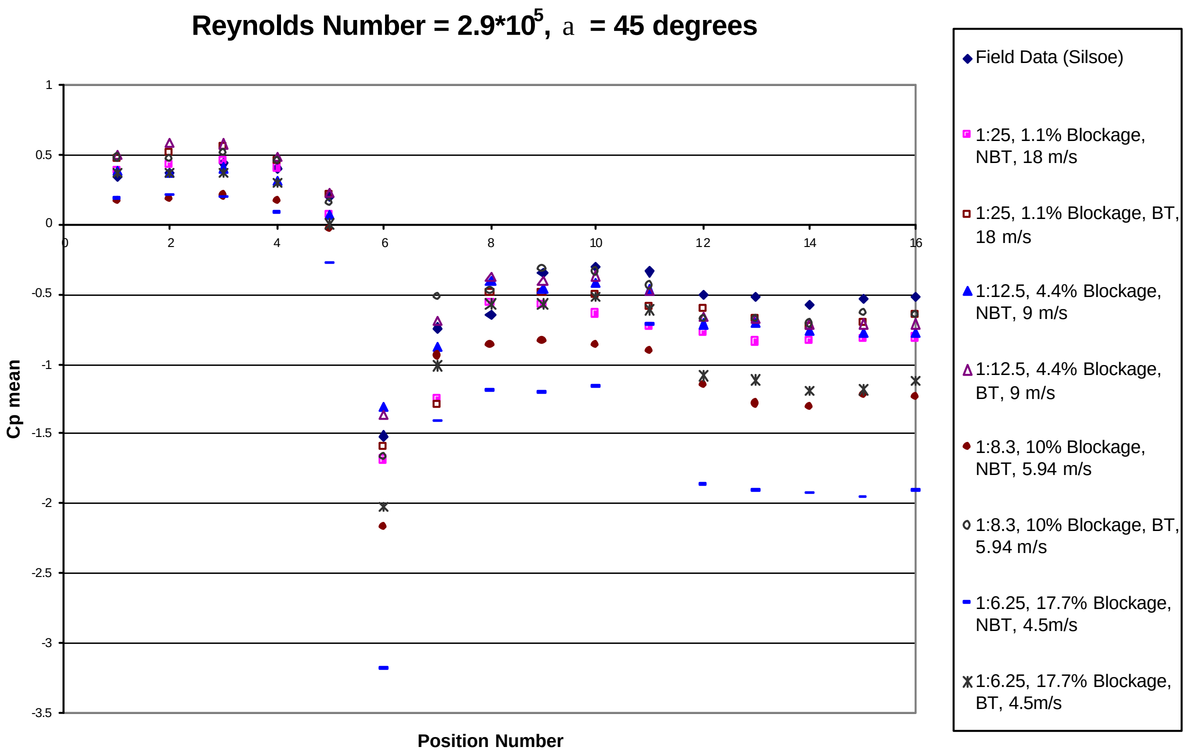


Figure 6b: Mean Pressure Coefficient vs Tap Location, α = 45 degrees

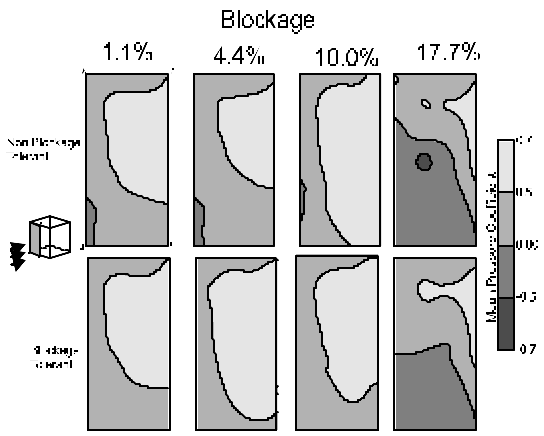


Figure 7a: Contour Plot for Windward Pressure, α = 0°

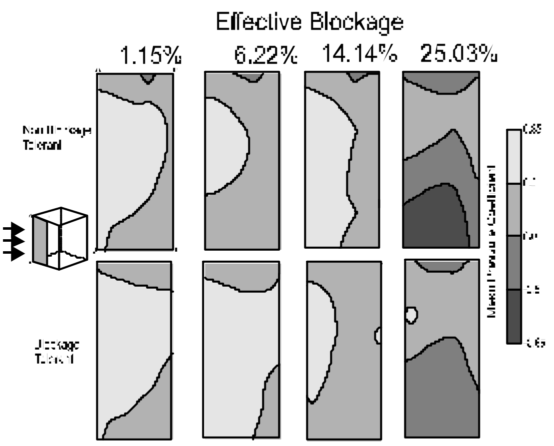
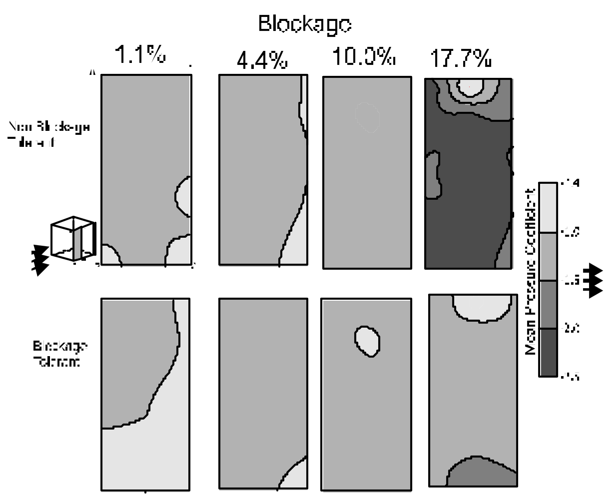


Figure 7b: Contour Plot for Windward Pressure, α = 45°



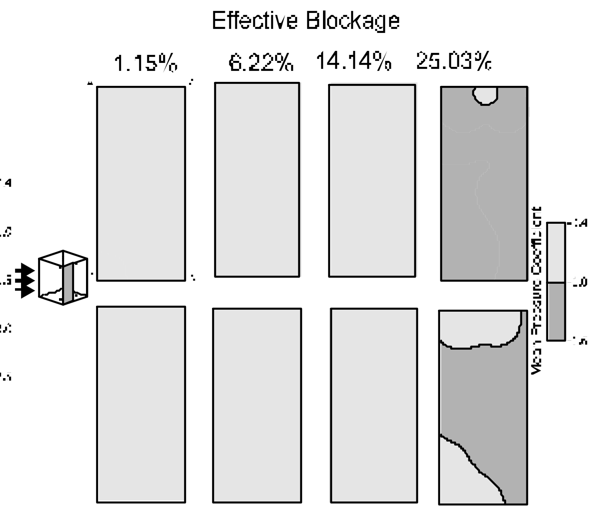


Figure 8a: Contour Plot for Side Pressure, α = 0

Figure 8b: Contour Plot for Leeward Pressure, α = 45°

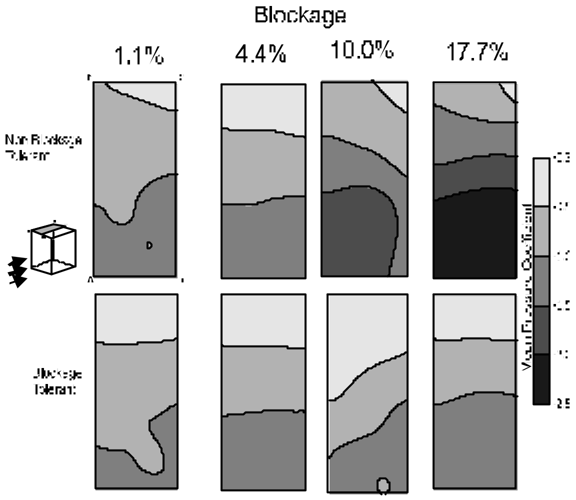


Figure 9a: Contour Plot for Roof Pressure, $\alpha = 0°$

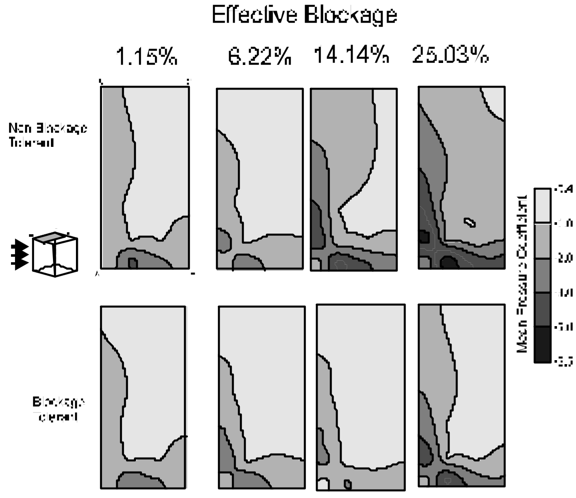


Figure 9b: Contour Plot for Roof Pressure, $\alpha = 45°$

4 CONCLUSIONS

It is apparent that the use of a transversely slatted blockage tolerant wind tunnel design has different effects on the different faces of the cube, with the results of the roof pressures benefiting the most by the upgrade. In the region of separation the higher pressures present due to the effect of the speed-up in the wind speeds over the roof in the non-blockage tolerant case is almost entirely eliminated by the BT setup.

In all cases it was seen that blockage effects are not apparent until approximately 7%. Substantial errors can occur in cases where the models have a blockage greater than this.

With the upgrade of Windtech's Boundary Layer Wind Tunnel to a Blockage Tolerant Boundary Layer Wind Tunnel, models with effective blockages of up to 20% in the case of roof pressures and up to 15% in the case of wall pressures show no substantial blockage effects.

REFERENCES

1 M.J. Glanville and K.C.S. Kwok: Further investigation of the blockage tolerant windtunnel technique. Journal of Wind Engineering and Industrial Aerodynamics 69-71 (1997) 987-995

2 Full scale data has been provided to the authors by Roger Hoxey of the Silsoe Research Institute, UK

3 G V Parkinson and N J Cook: Blockage tolerance of a boundary layer wind tunnel. Journal of Wind Engineering and Industrial Aerodynamics 41-44 (1992) 873-884