A STUDY OF THE ACTUAL AIRFLOW OVER A PHYSICAL CONICAL TENSILE MEMBRANE MODEL

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ABSTRACT:

Knowledge of the airflow pattern and rate in and around fabric membrane structures is still relatively unknown compared to the existing knowledge of more conventional structures. This paper reports qualitative wind tunnel experiments, which were conducted using a number of physical models representing a simple conical membrane structure. Horizontal, inclined, open and closed apex cases were explored for a variety of cone rise/diameter ratios and apex height/diameter ratios. Monitoring of the air velocity was carried out on a grid of 84 different points for each configuration. In this paper only six of the cases monitored in the wind tunnel are reviewed. Using these results, the possible use of a conic tensile membrane structure's topology and orientation to enhance ventilation rates and airflow velocities within the covered space is discussed. It is concluded that there is a need for further research in this area, in order to fully realise the potential benefits offered by tensile membrane structures for modifying airflows in their vicinity.

Keywords: Tensile membranes structures; Environmental performance; Wind tunnels; Airflow visualization;

Introduction

Since the 1960's a large evolution took place in the fabric structures industry, as they became more complex with time, and designers have been able to keep up with the structural implications of this changing situation. However, environmental issues continue to be dealt with in a cursory manner, which is till today unable to satisfy the client's requirements. With the vast interest in these structures designers and manufacturers alike realised that if membrane enclosed spaces is to compete with other more conventional enclosures, a clear understanding of their environmental behaviour should be available for them. More to add that if membrane enclosed spaces were to achieve the same level of environmental performance as more conventional buildings, it would be necessary to develop tailored analytical techniques which could be used to assess the likely performance of various design alternatives[1]. One of the ways in which TMS may be used to improve environmental performance is to exploit the form to induce or enhance ventilation and air movement in and around the enclosure[2]. Project managers and architects now acknowledge the importance of ensuring a safe and comfortable wind environment in the vicinity of new buildings. They are beginning to realize the economic benefits in ensuring a favourable wind environment at areas that involve commercial activities. Although the theory of the potential flow of an incompressible fluid has been highly developed but it can be said that it still have limited applicability. The mathematical theory provide essential basis for extrapolation from model to full scale, but still the theory of the boundary layer motion is complex and requires a lot of time, and not as quick and handy as the wind tunnel experiments. For judging the performance of a building, a system or a particular technology to see whether it reaches the required comfort levels and its behaviour, we need a set of testing and evaluation tools. In the case of buildings considered for passive ventilation, experimental work is used for good understanding of the physical behaviour of building and the comfort of its users.[3] For the purpose of this research wind tunnel testing was carried out in order to understand the airflow behaviour around fabric membrane structure. As well as achieving the required conditions for the model tests with less time and cost, wind tunnel testing make it possible to determine the influence of various features of the design and of modifications to them in a manner which is usually fairly straight forward to plan, execute, analyse and relatively cheap[4]. This study focuses on the visualisation of “airflow patterns” around membrane structures, and how they vary with air speed and differing membrane geometry.

- Examine air velocity distribution around the structures.
- Investigate use of TMS form and topology to assist in achieving higher comfort levels with the occupied space or in the vicinity of the structure.

The Institute of Building Technology (IBT) Open Jet Wind Tunnel

The wind tunnel used for the testing of the airflow around different forms of tensile membrane structures is based on a small open jet wind tunnel developed for teaching purposes by Sexton[5] at the Building Research Establishments (BRE) in the late 1960s. The wind tunnel is designed to produce a wind profile similar to that of the natural wind; it has a maximum flow velocity of 6m/s and a working section of width 1m, height 0.75m and 2.25m length. A schematic plan of the wind tunnel with dimensions is shown in figure --. The wind tunnel has been extensively used by researchers in the IBT under various types of projects.

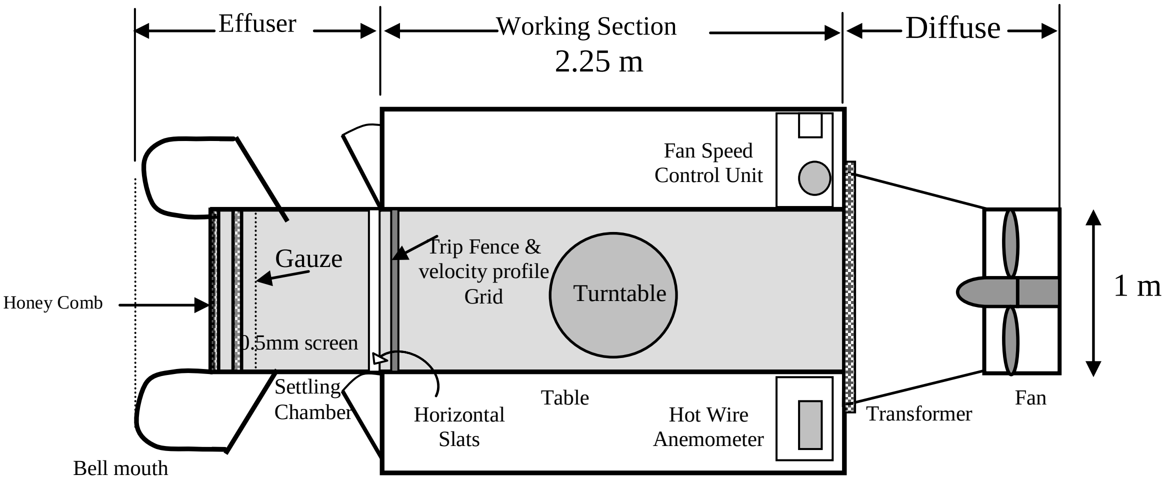


Figure 1. Schematic Plan of the IBT open jet wind tunnel (Drawing not to Scale)

The Choice of Form and Wind Tunnel Visualization

For this study the conic shape was selected being as one of the simplest and most frequently used fabric structure roof form. A series of wind tunnel tests have been undertaken to visualize the airflow pattern, then other experiments were done to determine the wind velocity under and around the structure. The tests where to understand the effect the form of the roof itself will have on the airflow, in order to assess in the design process and to enhance the natural ventilation and passive cooling techniques within such structures.

Airflow Visualization under and around the conical membrane

A smoke generator was used to visualise the trajectory of the airflow as it moved under and around the membrane. The models was set at 3 different heights without varying the diameter of the upper or lower rings, the chosen heights were similar to the ones used in the airflow measurements tests which were 3 cm, 7.5 cm and 17 cm high cone with closed and opened apex, at heights 20cm, 16cm and 12 cm from the base. The cones were tested at the straight and tilted cases for all of them. Also the same conditions were set testing a flat disc with the same diameter as the cones and at the same heights from the base.

a. *b.* *c.*

Figure 2. Wind tunnel experiment showing the effect on airflow of a conical membrane with closed apex

As can be clearly seen in figures 7(a) to (c), for a conical membrane with a closed apex, the airflow tends to be deflected downwards into the occupied area then bends upwards again when leaving the area underneath the structure. The results were the same in all the tested cases of the closed apex cones, except that it tends to bend have a more acute bend with the higher cone height as in the case of the 17cm high cone as shown in the figures below. This is not so pronounced in the case of the flat surface.

In the case of opened apex cone the part of the airflow tends to be shafted into the opening and the other follows the same path as what happens in the closed apex, this can be used to accelerate the airflow taking out the warm air and withdrawing in cooler air in hot climates. In case of tilting the cone towards the wind, this increases the airflow after entering the edge of the cone, and then it opens up in the rest of the area underneath the structure as shown in Figure 3 (a). Tilting the structure away from the wind results in the air entering at opened paths then it squeezes in to exit at the other end as in Figure 3 (b).

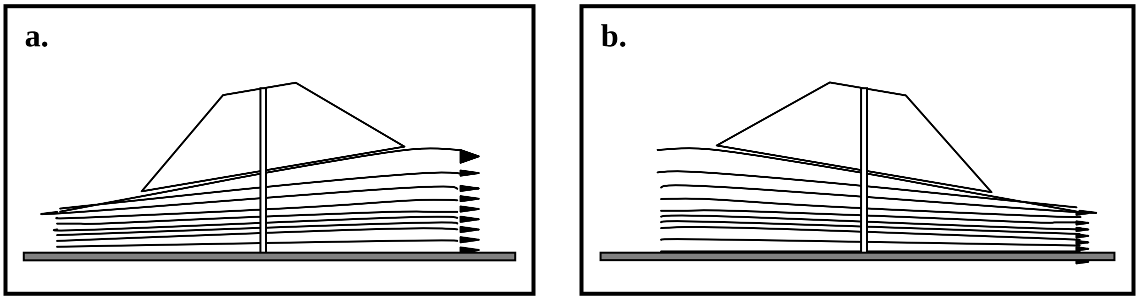


Figure3. (a)The airflow path for a cone tilted towers the wind with closed apex, (b) the airflow path for a cone tilted away

Monitoring of the Air Speed around and Under the Conical Shape

In warm weather even if it is high temperature having a higher air velocity moving around the body helps in cooling down the body by the use of evaporative cooling, and thus providing a higher level of human comfort, within the enclosed or semi enclosed space. The main objectives of this research were to investigate use of TMS to assist in ventilation of enclosed and/or uncovered spaces, or for modifying the air velocity in their immediate vicinity. To facilitate this, a hot wire anemometer was used to measure the airflow under and above a model of a conical membrane structure in order to investigate the effects of the structure's inclination and the shape of the cone itself as mentioned earlier in the paper (e.g. the height/width ratio of the cone, its height above the "ground" surface, etc).

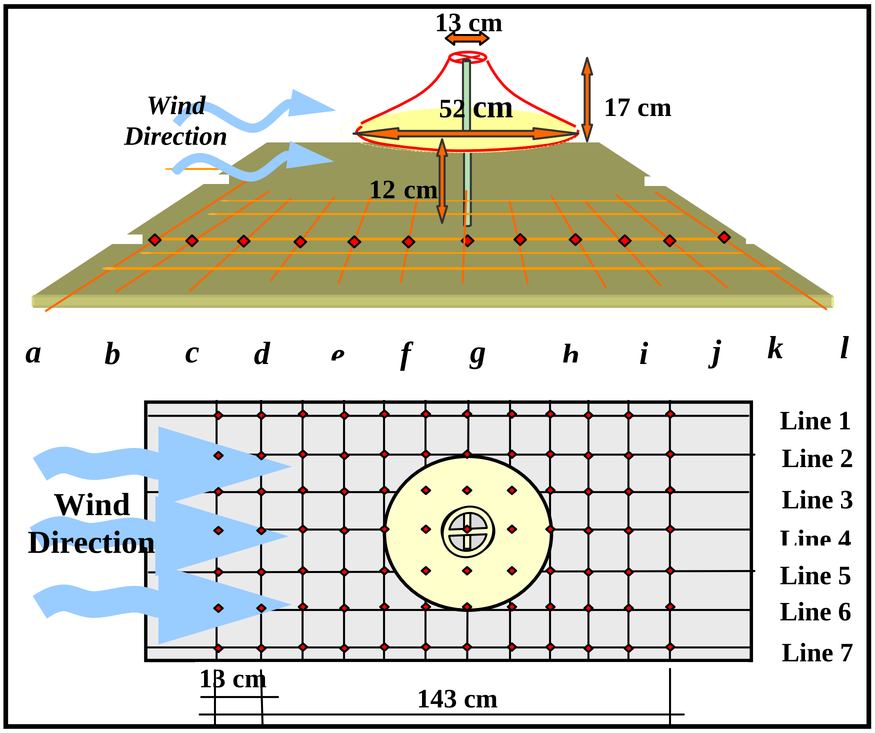
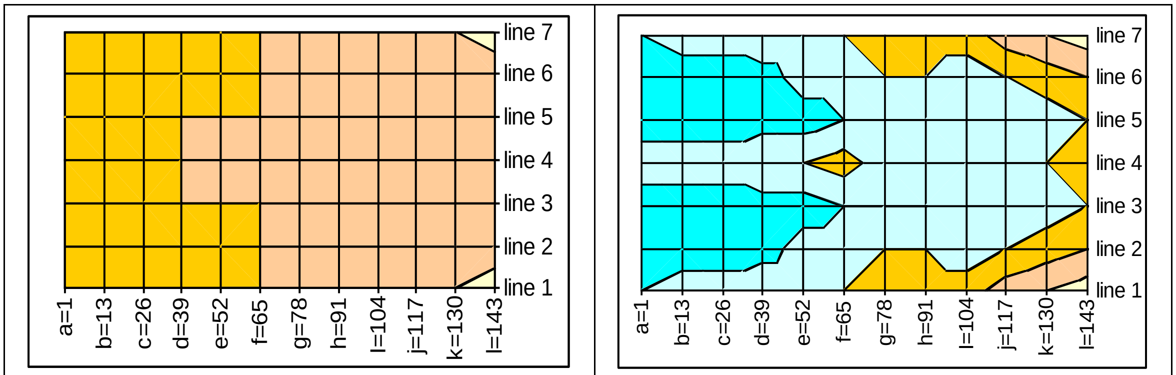
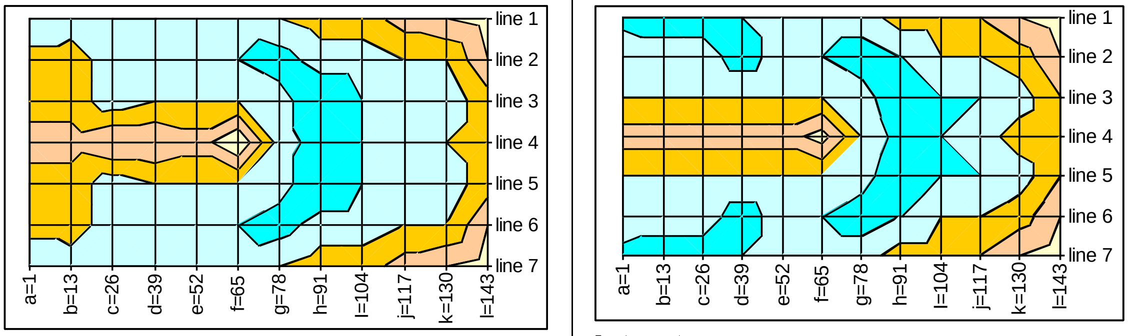


Figure 4. Perspective and plan of the conical membrane structure and the grid of air velocity measuring points.

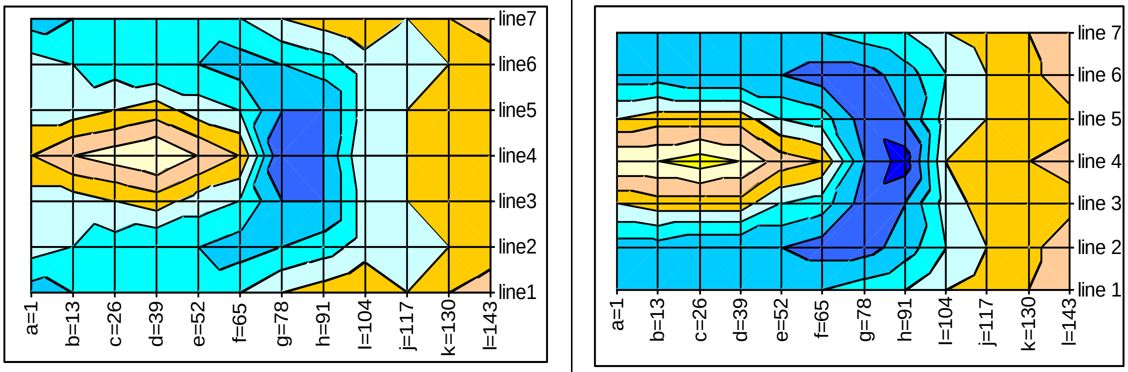
Figure 4 shows a perspective of the conical membrane model and the grid of measurement points using the letters (**a**, **b**, **c**,…) to denote rows, and the numbers (**1**, **2**, **3**…) to denote columns on the grid. The mast support for the cone is located at grid position **g4**. In all cases tested, the air velocity was measured at the shown 84 points using the single probe hot wire anemometer at 6.5 cm above the base. The points were located on a square grid of 13 cm, this being half the radius of the cone. Seven equally-spaced lines were determined on the wind tunnel table, symmetrically about the centreline in the direction of the wind flow, and the air velocity was measured at 12 equally-spaced points along each of these lines.



a. No Cone (NC) **b.** Flat disc roof (FR)



c. (SO3) **d.** (SC3)



e. (SO17) **f.** (SC17)

Figure 5. Airflow patterns at a height of 6.5 cm above the base where wind flows from left to right for (a) no cone; (b) the circular flat disc; (c) straight open cone at 3cm; (d) straight closed cone at 3cm; (e) straight open cone at 17cm; (f) straight closed cone at 17cm.

Figure 5 illustrates the variant air velocity pattern around and under the conical structure in the six cases referred to earlier in this paper. As seen in figure 5(a), when there is no cone at all the airflow remains steady and stable at almost all points then decreases slightly at positions remote from the wind. Figure 5(b) shows the air velocity under the circular flat disc, which has the same radius as the tested conical structure. It is clear from figures 5(b), 5(c) and 5(f) that although the airflow velocity is increased with the presence of the circular flat plate, the velocities are higher when the conic membranes are present.

In the case of SO3, Fig 5(c), it can be seen that the air velocity tends to be lower than control case (NC) to the windward side around the centreline of the cone and increases to its maximum immediately to the leeward. Air speed tends to be unstable at the windward side in almost all the open apex cases. In these cases an average reading is taken of the air velocity at that point. This fluctuation does not occur at the leeward side of the cone. Figure 5(d), case SC3, shows a slight change to the above as air velocity increases towards the outer edges of the area monitored and a drop of air velocity occurs getting closer to the centre of the cone at the point **f4**,

In case SO17, air velocity tends to decrease on the mid axis of the cone as in SO3, and then increase again as it passes the centre point of the cone to the leeward half. Also the highest air velocity is reached in the middle of the leeward half of the cone along the mid axis where air velocities reach its maximum as seen in figure 5(e). Airflow around SC17 tends to decrease more to the windward side just in the middle of the structure than in the open case and then increases significantly on the leeward half of the surface as seen in figure 5(f).

Conclusions

In this paper the reason for the wind tunnel experiment have been discussed. The techniques and equipments used in the wind tunnel investigations have been presented. Simple wind tunnel testing has shown that topology and orientation of a simple conical membrane structure may influence considerably the wind environment in its immediate vicinity. The results of wind tunnel testing revealed the need for further research in this area, in-order to fully realise the potential benefits offered by tensile membrane structures for modifying airflows in their vicinity and for their use as microclimate modifiers.

Preliminary results of the investigation show that higher airflow velocities are achieved within the enclosure under certain conditions, for instance when the cone is inclined towards the prevailing wind direction. This improved ventilation may enhance the comfort of occupants of the membrane enclosure, particularly in hot climates and reduce the demand for mechanical cooling systems (and consequently energy consumption). Detailed results and conclusions will be presented in a future paper.

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