Wind Socks, They Work!

M. Eaddy, W.H. Melbourne.
Department of Mechanical Engineering, Monash University

Abstract
A wind sock is a simple device used to indicate wind strength and direction at locations such as airports and bridges. This paper describes a wind tunnel experiment performed to determine convincingly the fluid mechanics of a typical wind sock. A wind sock is inflated by the wind, with some dynamic pressure recovery causing an internal positive pressure. The external pressure ranged from negative to slightly positive with stream direction, resulting in a net outward pressure force. It was found that only a proportion of the flow through an equivalent upstream area passes through the wind sock, with the remainder deflected externally around the sock.

Introduction
Wind socks are common place at airports, on bridges or in any situation where an indication of wind speed and direction is required. This paper stems from a question of how wind socks work proposed by a member of staff at Monash University. A discussion of the fluid mechanics of the wind sock followed, with one argument suggesting the pressure inside the wind sock must be lower than outside considering ideal flow and Bernoulli's equation due to the taper of the wind sock, and the other argument was the pressure can not be lower as wind socks do not collapse. Unconvinced by explanations of the wind sock operation by Professors of Fluid Mechanics and Graduate Students, it was insisted that wind tunnel measurements be performed to illustrate the fluid mechanics of a wind sock. Therefore, a small wind sock was acquired and setup for a wind tunnel experiment.

Method
The wind sock was made of heavy fabric to withstand adverse environmental conditions, such as high wind, rain and ultraviolet light. This construction did not allow pressure tappings to be installed. Instead a separate rigid model was constructed out of thin plywood that matched the dimensions of the fabric wind sock. A total of 20 pressure tappings were placed at 10 locations along the top generator of the rigid wind sock, as indicated in Figure 1. The tubing connecting the tapping to a transducer was 1500 mm long, since the experiments were only interested in mean pressures no correction was made to the data for tubing resonant response.
The fabric wind sock model was not supplied with calibration wind speeds, this was determined in the wind tunnel by gradually increasing the wind speed. The experiments were only concerned with the case where the wind sock was streaming horizontally and stable in the wind flow. Once a wind speed was achieved where this occurred the wind tunnel settings were recorded. The rigid model was then substituted for the fabric model and the pressure measurements performed at this wind speed. The pressure measurements were reference to a Pitot Static tube positioned upstream of the model. To illustrate the flow field around the wind sock smoke visualisation was performed. The smoke was

injected into the flow at two different locations in separate experiments. The first, at the wind sock centreline, and the second, 50 mm above the centreline. The smoke visualisation was recorded from the side using a digital video recorder.

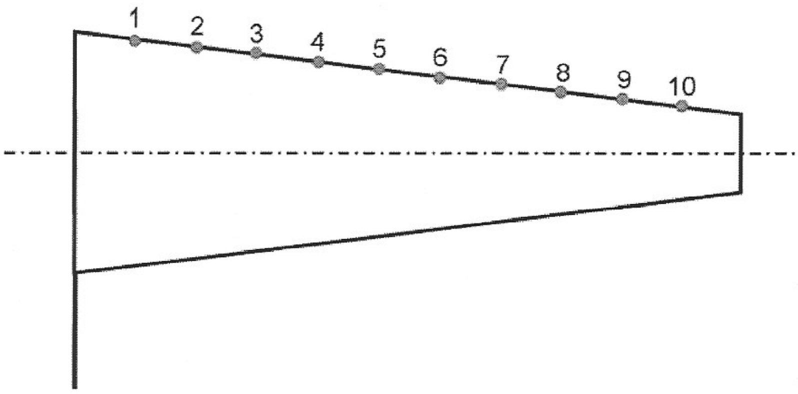

Figure 1: Schematic of wind sock indicating location of pressure tappings (● = differential pressure tapping)

Results

A wind speed of 15 ms^{-1} was found to fully inflate the wind sock and 'fly' steadily in the flow. Figure 2 shows the fabric wind sock on the left and the rigid model on the right at this wind speed.

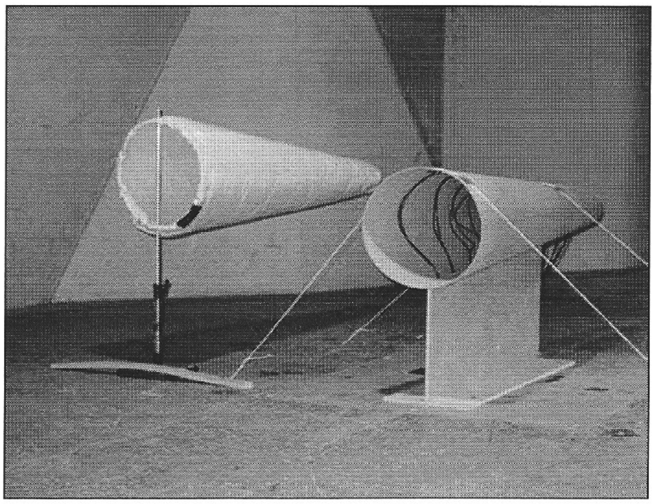

Figure 2: Fabric wind sock (left) and rigid model (right) at 15 ms^{-1}

Figure 3 presents the mean pressure coefficients for internal, external and differential pressures as a function of distance along the axis of the wind sock. The internal pressure was greatest at the inlet of the wind sock, approaching 90% of the flow stagnation pressure. There was not perfect dynamic pressure recovery due to not all the air passing through the upstream equivalent area of the entrance to the sock passing through the sock (see Figures 4 and 5). The internal pressure coefficients decrease with stream-wise distance as the taper of the sock causes the internal flow to accelerate, as expected by Bernoulli's equation. The external pressure coefficients were negative for approximately first 450 mm along the axis of the wind sock, then decreased to become slightly positive for the remaining distance. The negative pressures were caused by separation of the flow over the edge of the inlet. The differential pressure coefficients illustrate the pressure across the surface of the wind sock, with a positive differential coefficient indicating an outward acting pressure. The results show that the pressure difference was positive for the entire wind sock; hence it was inflated by the wind. The differential pressures suggest as the wind speed decreases, and hence pressure, the last half of the sock would collapse first, followed by the front half at a lower wind speed. This situation is common in atmospheric conditions where wind socks are observed with the rear half collapsed. The negative pressures caused by the front edge separation enable the front half to remain inflated at a lower wind speed.

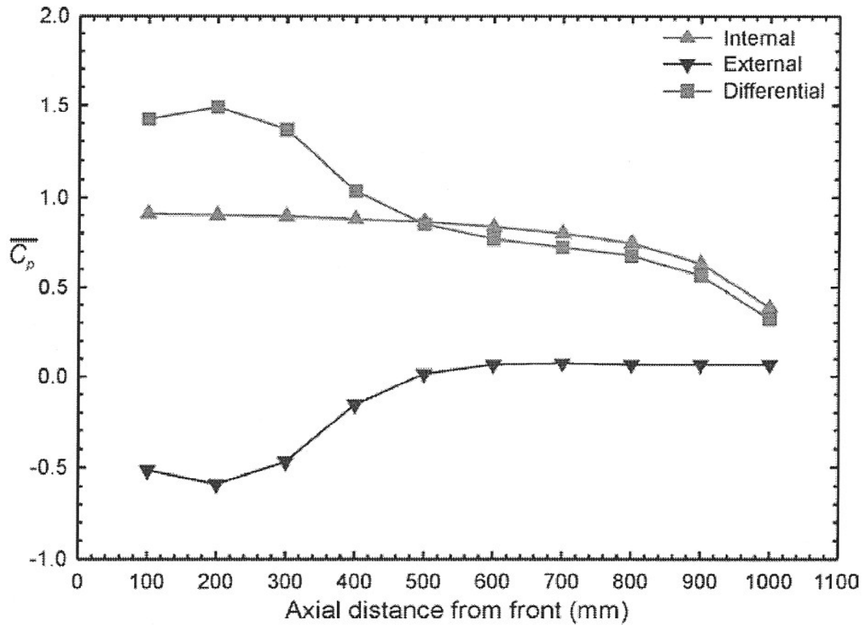

Figure 3: Mean pressure coefficients as a function of distance from front of windsock

The flow pattern observed from the smoke visualisation is given in Figure 4. The figure indicates the flow pattern observed around the wind sock and deflection of flow externally around the body. The figure includes reference points 0 to 3 where the Bernoulli equation has been applied using the measured pressure coefficients. Figure 5 presents the Bernoulli analysis for the reference points, noting that point 3 is outside the separating shear layer and indicates significant increase of velocity. The proportion of the onset flow that does enter the wind sock did increase in velocity due to the sock taper, exiting the sock as a higher speed jet with a vena contracta.

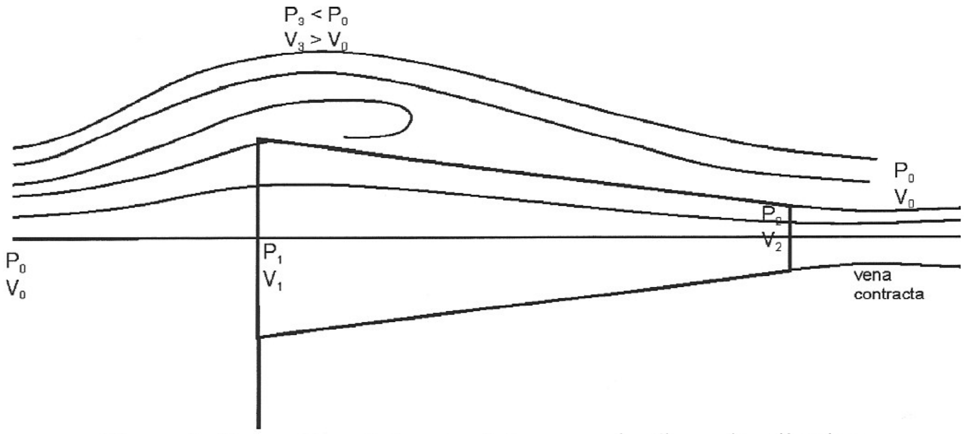

Figure 4: Streamlines determined from smoke flow visualisation

$$P_0 + \frac{1}{2}\rho V_0^2 = P_1 + \frac{1}{2}\rho V_1^2$$

$$\frac{P_1 - P_0}{\frac{1}{2}\rho V_0^2} = C_P = \frac{\frac{1}{2}\rho V_0^2}{\frac{1}{2}\rho V_0^2} - \frac{\frac{1}{2}\rho V_1^2}{\frac{1}{2}\rho V_0^2}$$

$$= 1 - \frac{V_1^2}{V_0^2}$$

$$V_1 = \sqrt{1 - C_P}\, V_0$$

$$At\,1\ C_P = 0.9 \rightarrow V_1 = \sqrt{0.1} \bullet V_0 = 0.32\, V_0$$

$$At\,2\ C_P = 0.4 \rightarrow V_2 = \sqrt{0.6} \bullet V_0 = 0.77\, V_0$$

$$At\,3\ C_P = -0.55 \rightarrow V_3 = \sqrt{1.55} \bullet V_0 = 1.25\, V_0$$

Figure 5: Bernoulli analysis of pressure field around wind sock (Point 3 is along a streamline outside separated shear layer)

Conclusions

The fluid mechanics of a typical wind sock have been investigated using point pressure measurements and flow visualisation. The investigation identified the fluid mechanics associated with wind sock operation. The wind sock is inflated by the wind, with some dynamic pressure recovery causing an internal positive pressure. Additional outward pressure force over the first half of the sock is provided by negative pressures caused by the separation of the flow across the inlet edge.

The flow visualisation showed that only a proportion of the flow through an equivalent upstream area passes through the wind sock, with the remainder being deflected externally around the sock.

Bernoulli's equation is applicable to the flow field around the wind sock with the exception of the separated flow region.