

Blockage Effects in the Calibration of Anemometer in a Wind Tunnel

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Abstract: Anemometers are commonly calibrated using wind tunnel systems. Due to the finite volume of the test section of wind tunnels, measurement results obtained in the wind tunnels often do not resemble those obtained under the condition of infinitely spaced boundaries as the blockage effects of anemometers cannot be neglected. This paper describes an experiment carried out to analyse the blockage effects of anemometers in a wind tunnel having effective test size of $\phi 180$ mm x 300 mm which covers the velocity range of 0.1 to 60 m/s.

Keywords: Wind tunnel, blockage effects, wind profiles, measurement uncertainty

1. Introduction

Wind tunnels are commonly used for the calibration of various types of air velocity meters ^[1-6]. However, due to the limited test volume, wind tunnels cannot fully realise the measurement conditions of infinitely spaced boundaries, and measurement results obtained may deviate considerably from an in situ measurement. Such deviations are mainly caused by blockage effects of the probe-under-calibration placed in the test section ^[7-8] of the wind tunnel. Ideally, the area blocked by the probe should be less than 1% of the effective cross-sectional area of the wind tunnel. However, it is sometimes difficult to realise this ideal measurement condition if space available for housing the wind tunnel is limited. For larger blockages, corrections for boundary layer for the calibrations are commonly applied to represent the infinite boundary condition ^[7-10]. This paper describes the effects of blockage sizes, positions and wind speeds on probe calibrations for blockages in the range of 2% to 70% of the effective area of a closed-loop wind tunnel, and shows how the blockage effects can be analysed and quantified.

2. Method of Experiment

The wind tunnel used for the experiment is shown in Fig. 1.

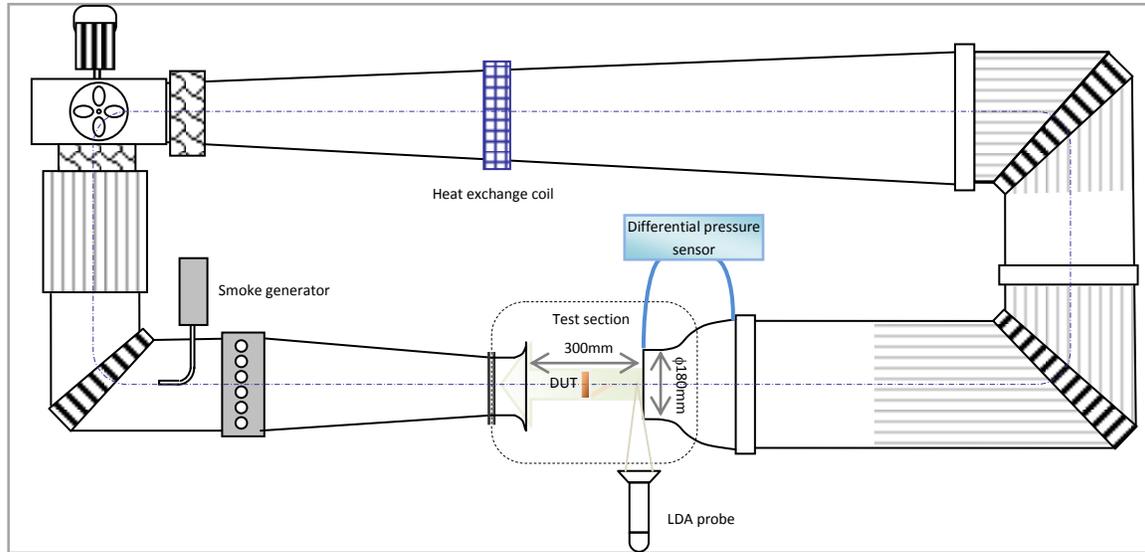


Figure 1: Schematic diagram of the wind tunnel

The wind tunnel shown in Figure 1 is capable of measuring air velocity in the range from 0.2 m/s to 60 m/s. Air velocity in the tunnel is measured by a differential pressure sensor with the probes connected to the inlet and outlet positions of the wind tunnel nozzle. This wind tunnel is designed to automatically compensate for the air speed drop based on the following equation:

$$V_{wt} = \frac{1}{\sqrt{1 - \beta^4}} \times \sqrt{\frac{2 \cdot \Delta P}{\rho}} \quad (1)$$

where

β : nozzle compression ratio

ΔP : the pressure drop across nozzle

ρ : density of air

When a blockage causes a reduction in the differential pressure value across the nozzle, the motor of the wind tunnel will be automatically accelerated to maintain the same differential pressure as the condition of no blockage. This method may be not sufficient to compensate for the loss in wind speed caused by a larger blockage size as the nozzle exit profile is distorted.

As shown in Figure 2, a set of disks of different sizes were used to represent various blockage areas relative to the nozzle exit area. Table 1 shows the percent blockages, which are in the range of 2% to 70%, and penetration rates of the disks.



Figure 2: Blocking disks and the experimental setup

Reference Number	Desk 1	Desk 2	Desk 3	Desk 4	Desk 5	Desk 6	Desk 7	Desk 8
Percent blockage	2%	4%	6%	8%	10%	30%	50%	70%
Penetration rate	25%	25%	9%	9%	9%	9%	9%	9%

Table 1: Percent blockage of the test disks

A Laser Doppler Anemometer (LDA) was used to detect the air velocity distributions at the front of the nozzle.

3. Results and Discussions

3.1. Blocking Effects Due to Size of Blocking Area and Wind Speed

Without any object disturbing the wind flow, the wind profile at the front of the nozzle should be uniform laminar flow. Any blockage will cause the wind profile to be distorted and the velocity reduced. To simulate the blockage, each of the blocking disks was placed in turn at the calibration position which is about 115 mm away from the exit edge of the nozzle. Wind profiles corresponding to the various blockage sizes at the wind speed of 1 m/s is shown in Figure 3.

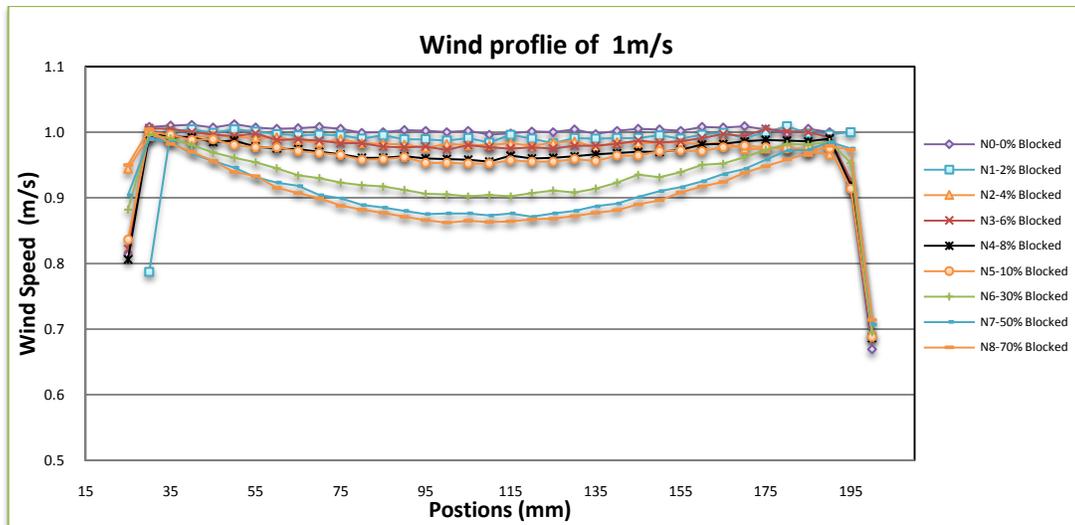


Figure 3: Wind profiles in front of the nozzle with the blockage areas from 2% to 70%

The wind profiles were measured at about 5 mm in front of the nozzle. The results show that wind speed progressively reduced at the top center of the profile caps, and the reduction became more significant with increasing blockage areas. When the blockage was bigger than 10%, the wind profiles became seriously deformed.

The study on wind profiles associated with different wind speeds was carried out using Disk 3 which has the blockage of 6%. It was found that the blockage effects decreased when wind speed increased. Figure 4 shows a comparison of blockage effects at speeds of 1 m/s and 10 m/s. The mean speed lost at 1 m/s was about 0.41% more than that of 10 m/s.

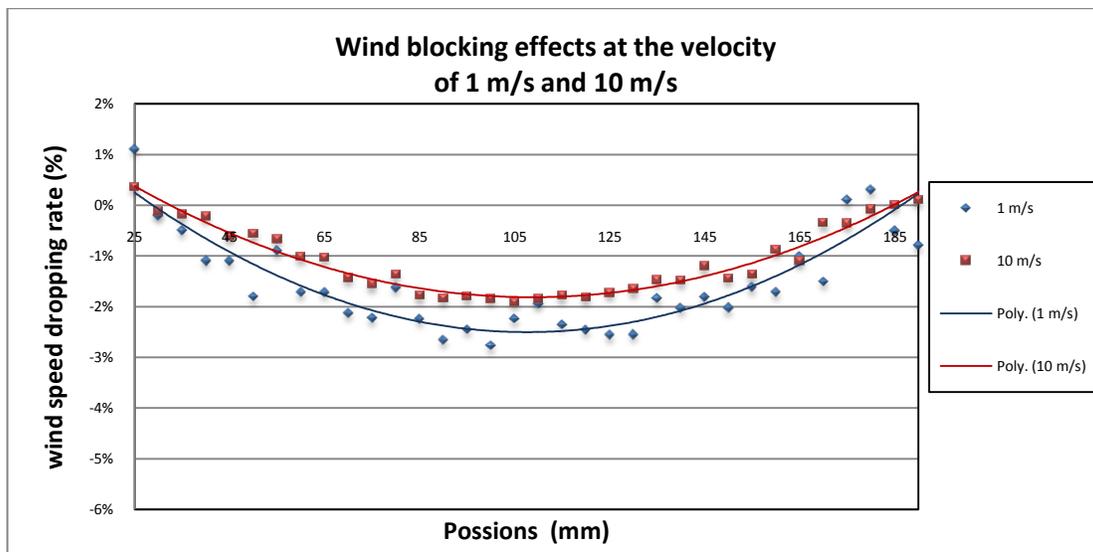
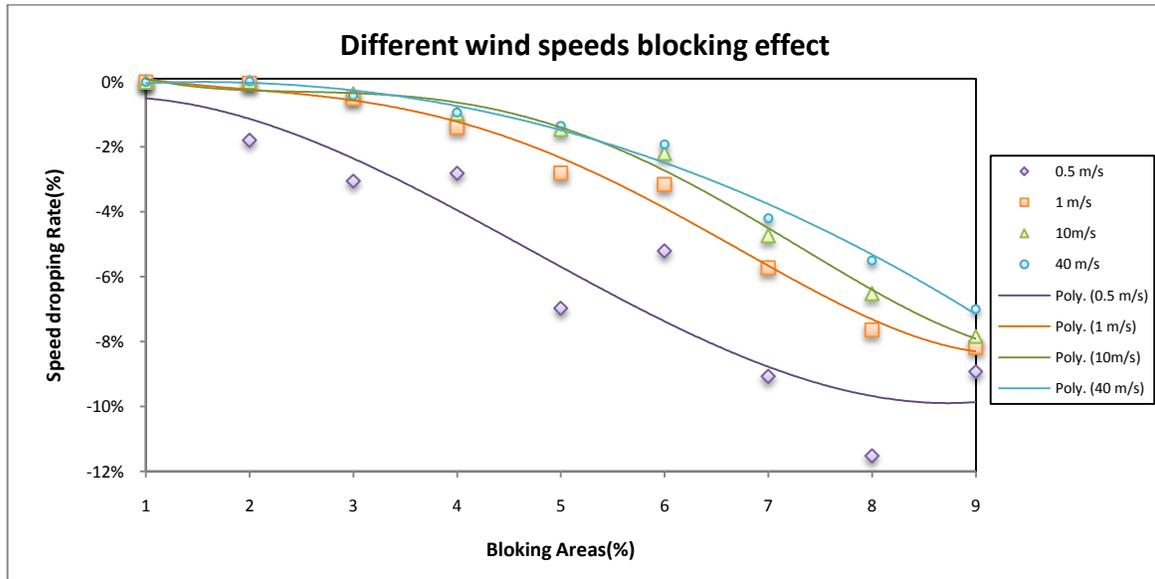


Fig.4 Wind profiles of blocked tunnel at wind speed of 1 m/s and 10 m/s

Tests were also carried out to investigate the reduction in wind speed at 0.5 m/s, 10 m/s and 40 m/s. The results are shown in Figures 5 and 6.



1	2	3	4	5	6	7	8	9
No blockage	2% blocked	4% blocked	6% blocked	8% blocked	10% blocked	30% blocked	50% blocked	70% blocked

Figure 5: Blockage effects for different wind speeds

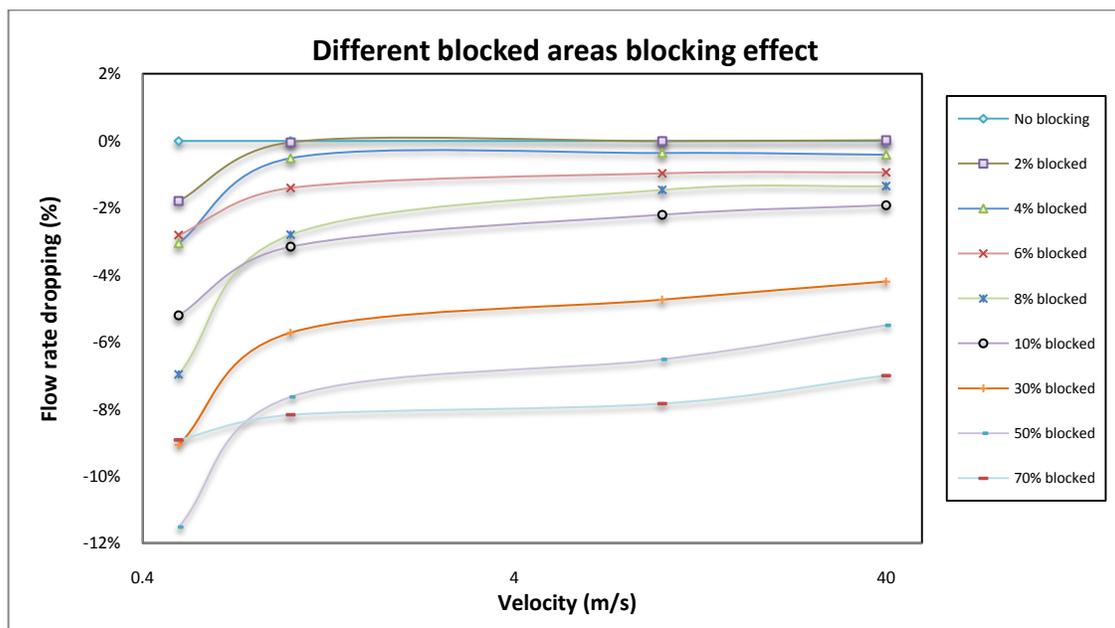


Figure 6: Blockage effects for different blockage areas

The effective flow rates drops were calculated using following equation:

$$D(v) = \frac{\oint f(v)dv}{\bar{v}_{nb}} \cdot 100 \% \quad (2)$$

where

v : velocity at front of nozzle

\bar{v}_{nb} : mean velocity at front of nozzle without blocking object

The experimental results show that the blockage effect is greatly influenced by both the size of blockage area and wind speed. The size of blockage area was the main reason that the effective flow rate was lower than the setting flow rate by 0.5% to 12% as shown in Figure 6. At wind speeds below 1 m/s, the drop in wind speed became more significant. This is due to difficulties in detecting pressure change across the nozzle using differential pressure at the lower speed range, and hence speed reduction was insufficiently compensated.

Variations in the wind blowing speeds caused relatively smaller change on blockage effect. The blockage effect reduced with increasing wind speed. Figure 5 shows that the blockage effects were within 2% when the flow rate was higher than 1 m/s with blockage areas less than 10%.

3.2. Distance to the Exit Edge of Nozzle

Figure 7 illustrates the blockage effect for different meter positions. At a distance of 100 mm away from the nozzle exit, the presence of the meter had no noticeable blockage effect, but moving the meter to about 35 mm from the nozzle exit caused a drop of 1.4% in mean velocity.

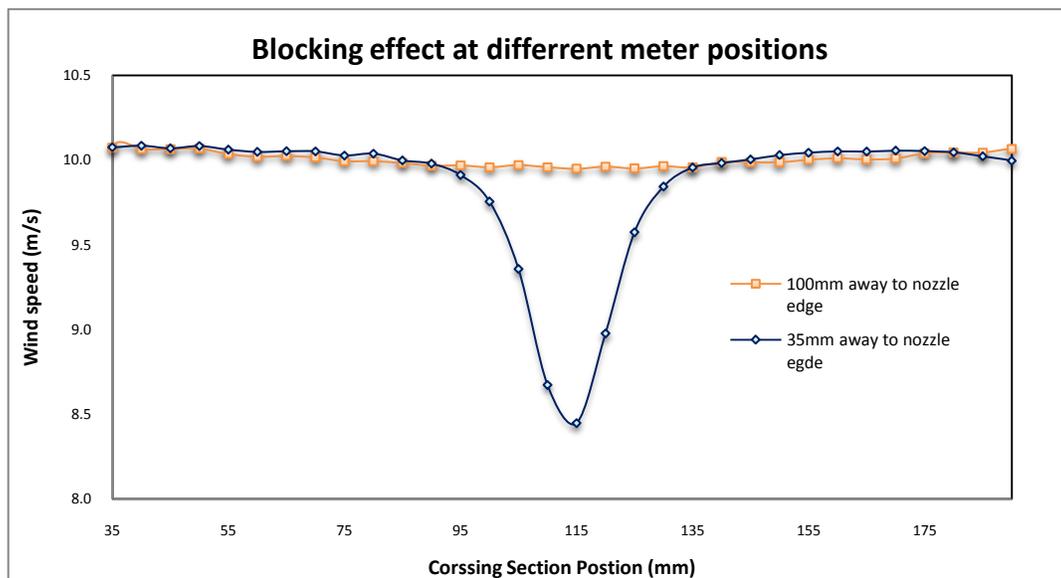


Figure 7: Blockage effects at different meter positions

Different types of anemometers were also investigated. A thermal anemometer with the 2% effectively blockage area and a fan-type anemometer with 30% effective blockage area were used to measure the blockage effects at positions along with the center axis of the nozzle. The measurement results are shown in Figure 8.

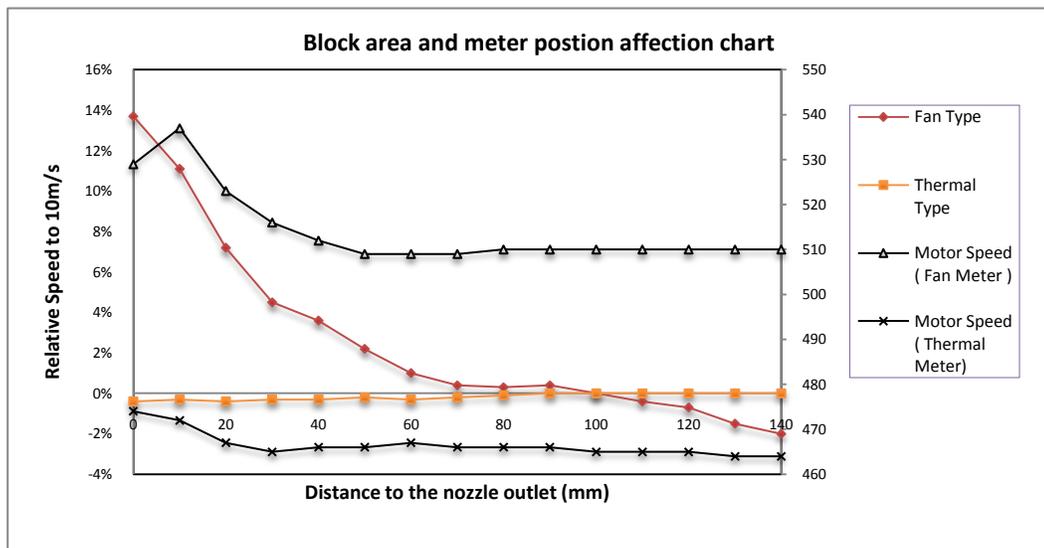


Figure 8: Blockage effects of thermal-type anemometer and fan-type anemometer

The deviation was negligible when the thermal anemometer was placed at positions 90 mm or more away from exit edge of nozzle. The motor accelerated only when the meter was set up nearer to the nozzle, at a distance of 30 mm or less, and compensation fell short by an amount of up to 0.3% at these positions.

For the fan-type meter, the measured results varied significantly with the location of the meter. Blockage was detected by the wind tunnel when the meter was placed at 100 mm or less away from the nozzle. Correct wind speed could be obtained only at positions of at least 100 mm away from the nozzle exit edge. Apparently, placing the meter closer to the nozzle caused deformation of wind profiles, leading to deviations in the readings. The effective blowing area reduces at distances of more than 100 mm away from the nozzle exit edge, causing the meter readings to drop.

3.3. Changes in Meter Profile

If wind profile is deformed, the meter's profile is likely to deviate from the profile obtained under the infinite boundaries conditions. Figures 9 and 10 show the meter's profile observed under wind profiles of differing deformations. A more seriously deformed wind profile caused greater blockage effect and lowered the effective wind speed.

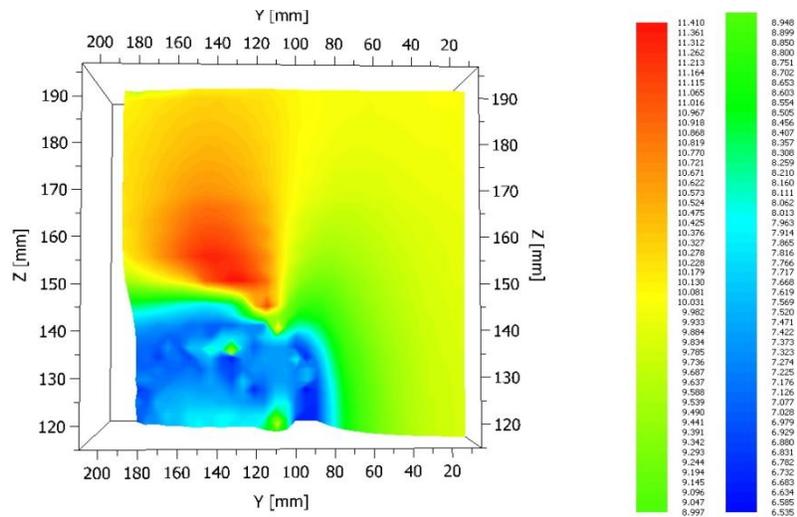


Figure 9: Blockage effects of Disk 3 at 100 mm away from the nozzle edge

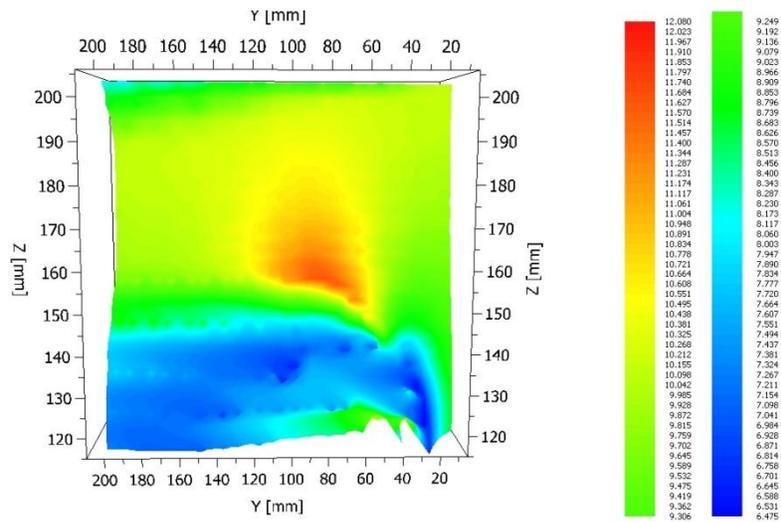


Figure 10: Blockage effects of Disk 3 at 40 mm away from the nozzle edge

Figure 11 shows a comparison of profiles at the positions of 40 mm and 100 mm away to the nozzle exit edge using Disk 3 (6% blockage area). The effective velocity dropped by about 1% due to this influence.

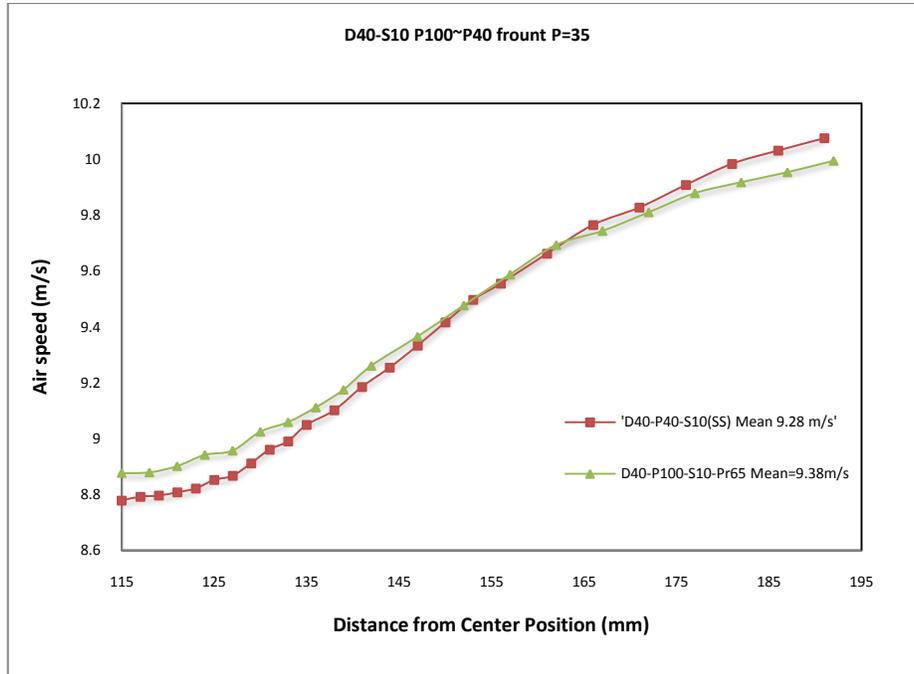


Figure 11: Comparison of the deformation of meter wind profile at 10 m/s

4. Conclusion

Blockage effects can be clearly observed when the velocity meter was calibrated in a limited test volume. To fully correct for the blockage effects, the method of differential pressure technique is insufficient to represent an infinite boundary condition. The experiment showed that influencing parameters that need to be accounted for are: blockage area (A_o); wind speed (v); distance to exit edge of nozzle (l); and the deformation of meter profiles (d). A full correction is therefore a function of all the influencing parameter, that is $C = f(A_o, v, l, d)$. The main influence of blockage effect is the size of blockage area. The most effective correction is for the blockage size smaller than 10%, at wind speed higher than 1 m/s. Placing the meter about 100 mm away from the exit edge of the nozzle in the wind tunnel minimises blockage effect, while keeping the blowing area sufficient large.

Blockage effect due to varying meter profiles was about 1%. However, infinite boundaries condition could not be obtained through this experiment. Different types of meter also have different structures. The resulting complex aerodynamic issues make it difficult to construct a general correction model. Further works will be done to address this influencing factor.

Acknowledgment

The authors are grateful to his colleague Mr. Tay Tack Hwa, for undertaken the work of data collection.

References

- [1] Wu Jian, Realisation of Primary Air Velocity Standard Using Laser Doppler Anemometer and Precision Wind Tunnel, XIX IMEKO World Congress, Conference proceedings, September, 2009.
- [2] Vern E. Bean, New Primary Standards for Air Speed Measurement at NIST, 1999 NCSL Workshop & Symposium, 1999, 413-427.
- [3] Yoshiya Terao, Mijndert van der Beek, T. T. Yeh and Harald Müller, Final Report on the CIPM Air Speed Key Comparison (CCM.FF-K3), October, 2007
- [4] Harald Müller, Thomas Lehmacher, Volker Strunck, Dietrich Doppeide, 5th International Symposium on Fluid Flow Measurement: Proceedings, 2002.
- [5] Noboru Kurihara, Yoshiya Terao, Masaki Takamoto, LDV Calibration for the Air Speed Standard Between 1.3 to 40 m/s, 5th International Symposium on Fluid Flow Measurement: Proceedings, 2002.
- [6] Cheng-Tsair Yang, Jeng-Yuan Chen, Jiunn-Haur Shaw, A New Air Velocity Standard by Using LDV and Wind Tunnel at CMS. 12th international conference on flow measurement, conference proceedings, 2004. 110-116.
- [7] M K Khan, K A MacKenzie and H H Bruun, The effects of blockage correction in hot-wire probe calibration facilities, J. Phys. E: Sci. Instrum. 20 (1987). Printed in the UK, 1031-1035
- [8] W. F. GOULD, Wake Blockage Corrections in a Closed Wind Tunnel for One or Two Wall-Mounted Models Subject to Separated Flow, Technical Report of Aerodynamics Division. N.P.L. London.
- [9] Deepak Sahini, B.Tech.Wind Tunnel Blockage Corrections: A Computational Study, a thesis in Mechanical Engineering, Texas Tech University.
- [10] Jan-Ake Dahiberg, A Investigation of Wind Tunnel Blockage Effect on Cup Anemometer Calibration, Technical Report, FOI-R-2006-SE