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REALISATION OF A PRIMARY AIR VELOCITY STANDRAD USING LASER DOPPLER ANEMOMETER AND PRECISION WIND TUNNEL

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Abstract: A primary air velocity meter calibration standard comprising of a precisely controlled wind tunnel system and a Laser Doppler Anemometry (LDA) system was developed for the calibration of air velocity meters from 0.2 m/s to 60 m/s with measurement uncertainties of less than 0.18% to 0.63%. The LDA system is used to verify the wind speed in the test section of the wind tunnel, and provide traceability to the SI for air speed measurements.

Keywords: air velocity measurement, wind profiles, measurement uncertainty

1. INTRODUCTION

Air velocity measurements are essential in many industry sectors such as biomedical, chemical, pharmaceuticals and semiconductors, as well as in applications relating to environmental protection. Currently, velocity meters are commonly calibrated using a wind tunnel in which the air speed is measured by means of pressure difference transformation. This method is, however, limited to a small measurement range due the ineffectiveness of Bernoulli's law at low speeds and the blockage effect of the velocity meter (DUT) at high speeds. An LDA system, on the other hand, has the advantage of a wider measurement range, being non-invasive and can be used to provide traceability to the SI[1]. Therefore, the primary air velocity standard at NMC uses an LDA system to measure the air velocity. Another critical part that has a major influence on air velocity measurement is the wind profile in the test section of the wind tunnel. To achieve highly uniform wind profiles, a precisely controlled wind tunnel system is used. The turbulence intensities along the cross-section and flow direction are measured using the LDA. The long term stability of wind tunnel was also evaluated.

Fig. 1. NMC's primary air velocity standard

2. MEASUREMENT FACILITY

2.1 Wind tunnel

The wind tunnel system used is shown in Fig. 2. To house the entire system in a confined space, a closed loop wind tunnel was chosen since an open tunnel would limit the size of the test section, resulting in serious blockage effect. The system works at around ambient pressure and temperature. Air is discharged from a contraction nozzle with a contraction ratio of 1:4 into the test section having a dimension of 0.5m (l) x 0.6m (w) x 0.8m (h). After passing through the velocity meter, the air is sucked back into the system via a five-degree one meter long diffuser. The blower is powered by a 3-kW AC motor that is automatically controlled by feedback signals from the wind speed measurements to stabilise the air velocity. A cooling coil is situated between the drive motor and contraction nozzle to stabilise air temperature.

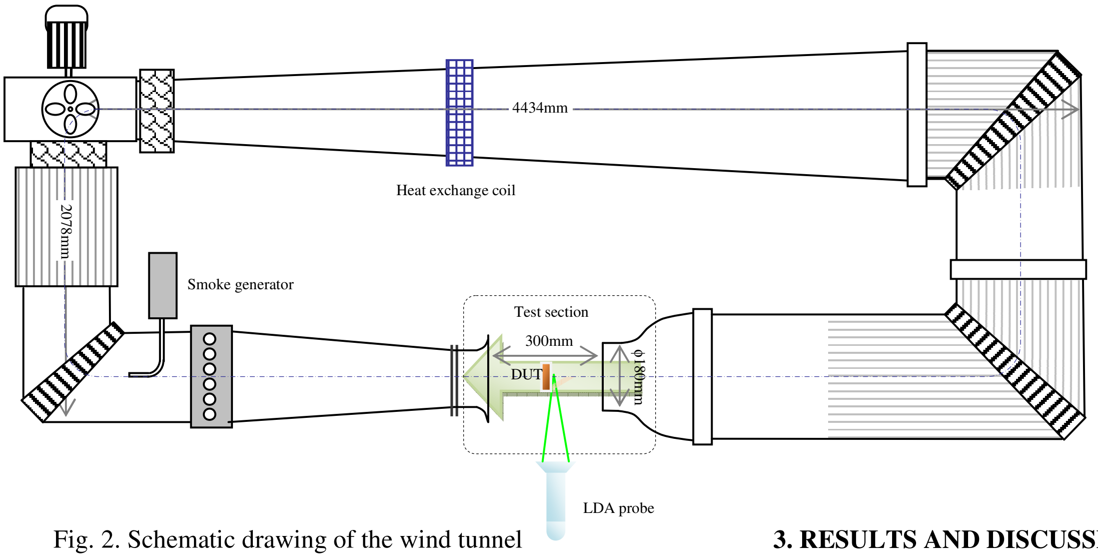

Fig. 2. Schematic drawing of the wind tunnel

2.2 LDA system

The LDA system measures wind speed by detecting the moving speed of particles carried by the wind. The commercially available LDA system, the FlowLite made by DANTEC, has a wavelength of 532 nm and continuous output power of 200 mW. The optical probe for air speed detection is mounted on a 3D traversing system with the maximum travelling distance of 1.1 m and 0.1 mm resolution, and is capable of scanning the entire test section.

The LDA system has been calibrated against a flywheel with the known rotating speed and radius[2][4]. The expanded uncertainty of the calibration was 0.07%.

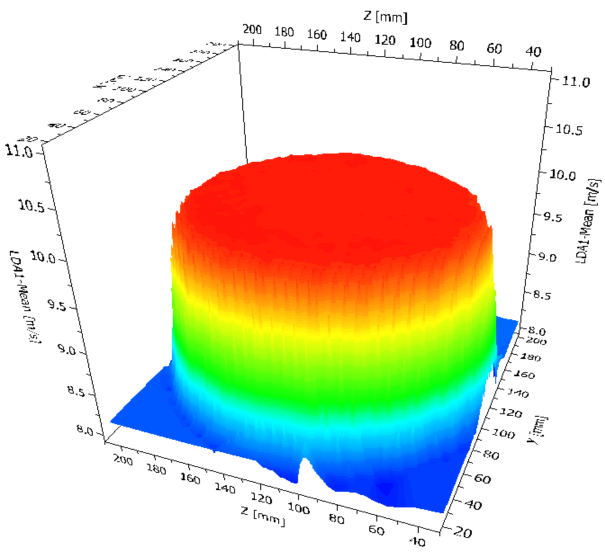

Fig. 3. Wind profile of 10 m/s

3. RESULTS AND DISCUSSION

3.1 Characterisation of wind profiles

Measurements of wind profiles were made from 0.2 to 60 m/s. The 10 m/s wind profile, measured at downstream positions about 100 mm away from outlet edge of the nozzle, is shown in Fig. 3. The uniformity of wind velocity within the top-hat circular area is within ± 0.012 m/s.

The cross-section wind profiles measured for other speeds are shown in Fig. 4, which shows that the uniformity at the top-hat areas are better than ± 0.002 m/s to 0.2 m/s as expected.

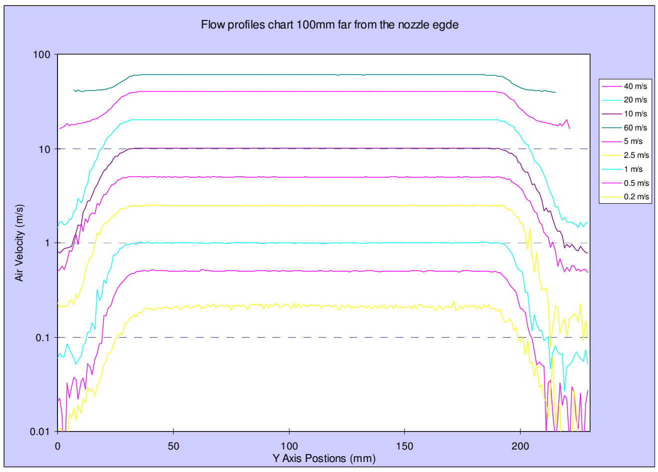

Fig. 4. The wind profile charts of air speed from 0.2m/s to 60m/s

The velocity changes in the horizontal direction were measured along with the axial line of nozzle as shown in Fig. 5. The speed changes were found to be from 0.01m/s to 0.3 m/s.

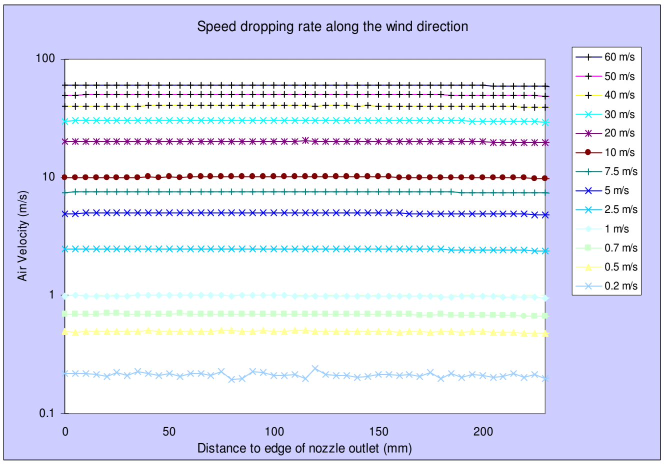

Fig. 5. Speed variation along the horizontal direction

3.2 Measurement uncertainty

Air velocity measurement using the system described above is a combined effect of: measured velocity from the LDA, uniformity of wind profiles, and meter blockage effect[3][5]. Air speed of anemometer V_{DUT} can therefore be expressed as:

$$V_{DUT} = V_{LDA} * C_w * C_b + Error \qquad (1)$$

Where, V_{LDA} denotes the measured velocity by LDA; C_w is the corrections factor due to the turbulence intensity of wind profiles and flow-field distribution as well as the long term stability of wind tunnel; C_b is the correction factor due to meter blockage effect. The measurement uncertainty of air velocity can thus be expressed as:

$$u(v)/v=((u(V_{LDA})/V_{LDA})^2+(u(C_w)/C_w)^2+(u(C_b)/C_b)^2+(u(DUT)/DUT)^2)^{1/2} \qquad (2)$$

3.2.1 Turbulence intensity

The turbulence intensity was evaluated using the LDA and a 2D ultrasonic velocity meter. The LDA measured the velocity variations along the wind directions while the 2D ultrasonic meter was employed to detect changes in flow direction.

The turbulence intensity of wind tunnel scanning along the central surface of the test section at speed of 10 m/s is shown in Fig. 6. The average turbulence intensity within the 80% effectively working boundaries is 0.012 m/s.

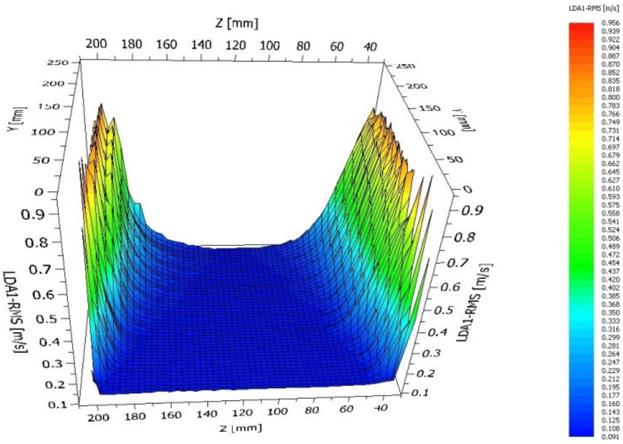

Fig. 6. Turbulence intensity of wind tunnel at velocity 10m/s.
Where: **y** is the distance to the nozzle outlet;
z is the vertical positions at the central surface of test section.
LDA1-RMS (Root Mean Square) is the turbulence intensity effect detected by LDA

The turbulence intensities at other velocities, which were detected by LDA, are shown in Fig. 7. The intensities across whole measurement range are less than 0.045 m/s.

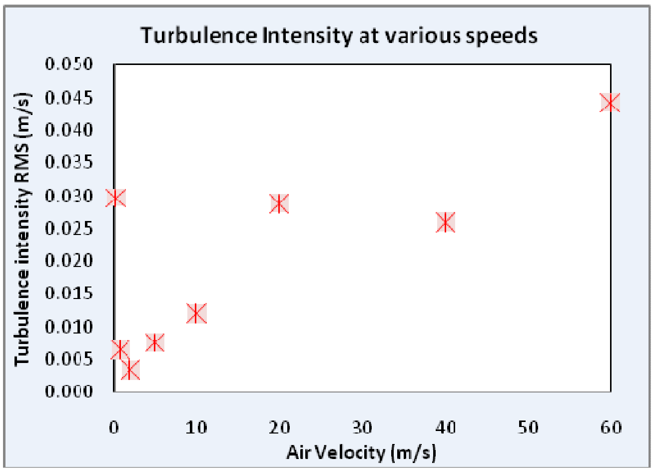

Fig. 7. Turbulence intensity of wind tunnel

3.2.2 Longer-term stability

The wind flow speed in the tunnel is automatically controlled using the feedback signals from the measurement of pressure drop across the nozzle. Its stability at the test section was investigated using the LDA at the reference position – 100 mm away from the edge of nozzle outlet. Various air velocities in the range of 0.2 m/s to 60 m/s were tested. The stability charts for 30 m/s and 0.2 m/s are shown in Fig. 8 and Fig. 9.

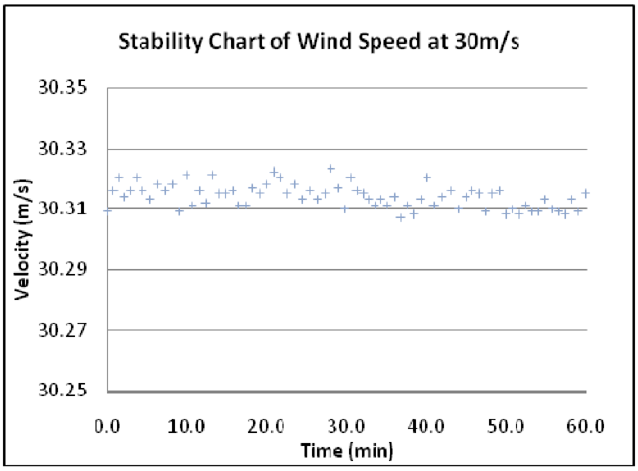

Fig. 8. The long-term stability of wind velocity at 30m/s

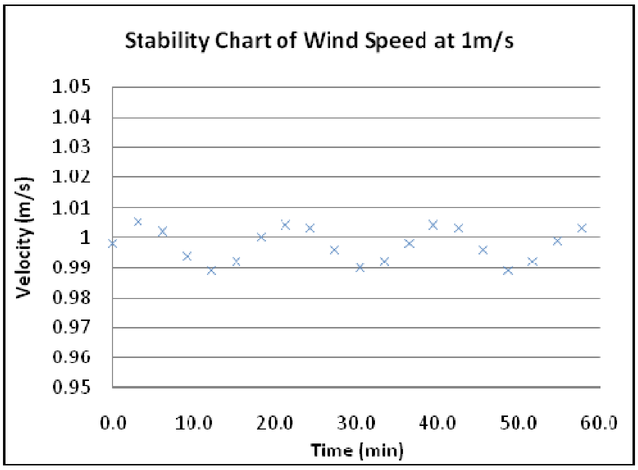

Fig. 9. The long-term stability of wind velocity at 1m/s

No obvious drift was found during the one hour test for each speed. The standard deviations of instability from velocities from 10 m/s to 60 m/s were in range of 0.009% to 0.013%, which is less than the effect due to the air turbulence. It is however found that the instability for velocity less than 1 m/s could be as high as 1% shown in Fig. 8. This was because of insufficient resolution of the pressure indicator which was used as the feedback signal to control fan speed. The affection due to fluctuation at the range below 1m/s was minimised to 0.05% or less through instantly correct the drift by using a hotwire anemometer.

3.2.3 The blockage effects due to meter under test

Since the wind tunnel test section has a confined volume, measurements obtained from the wind tunnel tests do not resemble those obtained from infinitely spaced boundaries, and the blockage effects of anemometers cannot be neglected. The correction factors have been applied to the measurement results which depend on the ratio of static blockage area to the cross-section area of the nozzle outlet as well as the penetration rate of the anemometers.

Most hotwire anemometers have the blockage area ratio between 0.01 and 0.03. An anemometer shown in Fig. 10 was analysed at velocity 10 m/s with the position at 100 mm away from nozzle outlet. The result is illustrated in Fig. 11. The correction was found to be less than 0.08 m/s when measurement points of LDA in front of the anemometer are about 30 mm. The correction is insignificant compared to the measurement results when the LDA measuring position is at 50 mm or more away from anemometer.

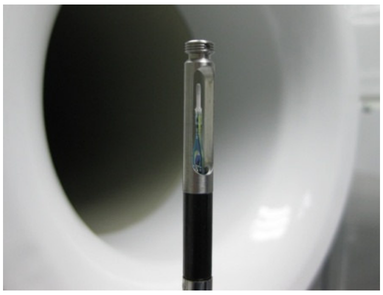

Fig. 10. Verification of velocity blockage effects using an anemometer

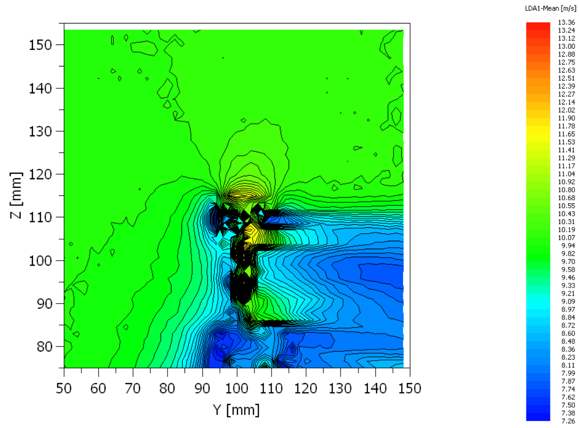

Fig. 11. The blockage effects of an anemometer at 10m/s.

Besides the hot wire anemometer, high blockage rate meters were also analysed using the same method. A cup air velocity meter as shown in Fig. 12 has the blockage rate of 0.12 to the nozzle outlet area. The result is given in Fig. 13

The correction was applied using Makell's blockage equations and found to be as large as 3% for measurements at 50 mm in front of the anemometer. This was also confirmed by the LDA scanning results as shown in Fig. 13. The uncertainty of the correction value was 0.07%. Furthermore analysis using CFD (Computational Fluid Dynamics) simulations found the similar results.

Fig. 12. Verification velocity blockage effects by using cup anemometer.

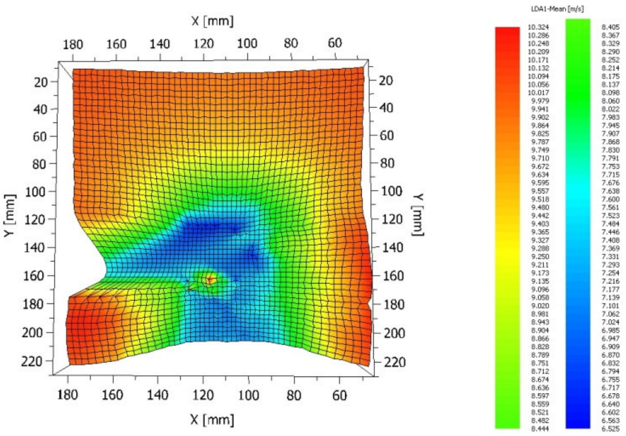

Fig. 13. The blockage effect of the cup anemometer

Where: **y** is the distance to the nozzle outlet;
x is the horizontal positions at the central surface of the test section.

3.2.4 Summary of uncertainty

Table 1 lists the source and values of the uncertainties. As shown in the table, the major uncertainty of the air velocity standard is due to the wind tunnel and anemometer blockage effects. The long term stability of the wind tunnel was also checked with LDA at each of the calibration speed and found to be within 0.05% or better. The uncertainty due to correction for the blockage effects can be limited to within 0.07%. The expanded measurement uncertainty is 0.63% or less depending on the range to be calibrated.

4. CONCLUSION

The primary air velocity standard setup was found to be capable of calibrating air velocity meters in the range of 0.2 m/s to 60 m/s. The expanded measurement uncertainty was shown to be within 0.18% to 0.63% after considering all the major influences from both the LDA and wind tunnel. The turbulence intensity, wind field distribution and long term stability of wind tunnel were characterised. Results of blockage effect can also be adopted for the future calibrations.

Table 1. Components and values of measurement uncertainty

Source		**Relative standard uncertainty $u(x_i)/xi$ (%)** Min	Max
Wind Speed measurement by LDA	Calibration	0.035	0.035
	Repeatability	0.005	0.005
The turbulence intensity		0.06	0.25
Uneven distribution of wind field	Horizontal directions *(a working distance of 100mm)*	0.01	0.05
	Vertical directions *(a work circular area with diameter of 50mm)*	0.02	0.05
The determination of blockage effects of meters		0.01	0.07
The long term stability of wind tunnel		0.01	0.05
DUT	Repeatability	0.02	0.05
	Resolution	0.01	0.01
Expanded uncertainty *with coverage factor k=2*		0.17	0.63

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REFERENCES

[1]. The air speed calibration at the national institute of standards and technology. N.E. Mease, W.G. Cleveland, Jr., G.E.Mattingly, and J. M. Hall. Technical document of Fluid Flow Group of NIST.

[2]. Air velocity sensor calibration intercomparison using LDA as the standard. Sanchez J .R, Harald Müller, Care Isabelle, Van Cordier, Seynhaeve J.M. 12th Int'l sym on application laser technique to fluid mechanics, 2004.

[3]. Final Report on the CIPM Air Speed Key Comparison (CCM.FF-K3). Yoshiya Terao, Mijidert van der B, T.T.Yeh and Harald Müller.

[4]. New primary standard for air speed measurement at NIST, Vern E. Ben, 1999 NCSL workshop and symposium, Pg 413~421

[5]. Uncertainty of NIST airspeed calibration, T.T.Yeh, J.M.Hall. Technical document of Fluid Flow Group of NIST.