Development of New High Air Speed Standard in Japan

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Abstract

NMIJ is developing a new standard system for high air speed over 90 m/s. The system is based on flowrates up to 1000 m^3/h generated by the primary standard facility of Japan. The flowrate is converted into air speed through a subsonic conversion nozzle whose outlet diameter is 60 mm, which is opened to the atmosphere. The flow velocity distribution across the exit plane of the conversion nozzle is measured then the flowrate through the nozzle is decomposed into air speed by using the measured flow velocity distribution. This paper describes measurement results of velocity profile in various conditions.

Introduction

Air speed measurement is playing important role in meteorological observation, aerodynamic designing, construction, and so on. To assure the accurate air speed measurements in the fields, two standard systems are now operating at NMIJ from 0.05 m/s to 40 m/s based on a towing carriage and a wind tunnel of the Göettingen [1] type with LDA system [2]. Since it is rapidly increasing the needs of accurate air speed measurement that is larger than 40 m/s, NMIJ is now developing an air speed standard system over 40 m/s up to more than 90 m/s.

According to KCDB published by BIPM [3], four countries have air speed standard system over 40 m/s as shown in Table.1. NMIJ will establish the high air-speed standard based on accurate flowrate generated by a flowrate standard system. The flowrate will be converted to the air speed by a conversion nozzle whose velocity field is measured precisely using Pitot tubes and hot wires. The air speed generated by the conversion nozzle will be then transferred to an Eiffel type wind tunnel that will be used to disseminate the standard. In the paper, the outline of the conversion nozzle and some measurement results of it velocity profile at the exit plane are described.

Table.1 CMCs lists of air speed standard more than 40m/s

NMI	Range	Conditions	Expanded uncertainty (k=2, 95%)
PTB (nozzle diameter 320mm)	0.5 to 65 m/s	Air speed, Ambient air	0.005 + 0.0035*U*), *U* speed in m/s
VMT/LEI	0.05 to 60 m/s		8.0 to 0.45%
VSL	1 to 50 m/s		1%
NIST	0.15 to 67 m/s		(0.006 + 0.0044*U*), *U* speed in m/s

The Conversion nozzle

The conversion nozzle uses an accurate flowrate generated by a closed-loop calibration facility that is a part of the middle-range air-flowrate standard system in Japan [4].

Closed-loop calibration facility

The closed-loop calibration facility can generates accurate flowrate up to 1000 m^3/h based on parallel connection of critical nozzles of up to 12 pieces. The CMC of the facility is 0.28% (k=2, 95%).

In order to establish the air speed standard, the facility is opened to the atmosphere at its calibration section. The conversion nozzle is put at the exit of the facility. Three blower compressors in the facility generate a stable flowrate through the facility by sucking air from the room. The critical nozzle chamber that measures the flowrate exactly is located at the downstream location of the inlet of the facility. Temperature and pressure measuring systems convert the mass flowrate measured by the nozzle chamber into the volume flowrate at the exit plane of the conversion nozzle.

Conversion nozzle unit

The conversion nozzle is shown in Fig.1. It has a 1:9 contraction with the exit diameter of 60 mm. It has three nets and one honeycomb in its upstream piping to make the flow field flat. It has pressure ports at important locations including the nozzle exit. The temperature of the flow is measured at the upstream of the nozzle unit.

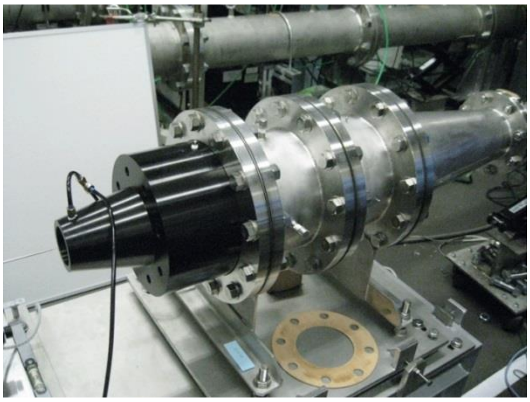

Fig. 1 Photograph of conversion nozzle unit

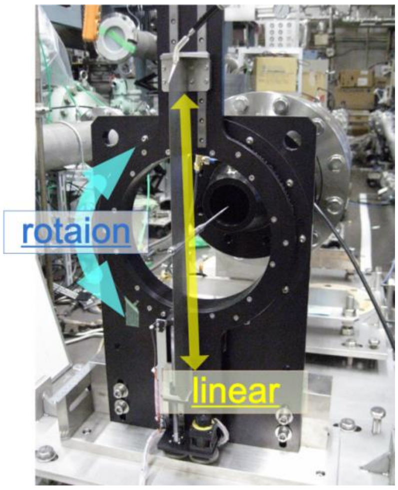

Fig. 2 Photograph of traverse device for the measurement of quantity distribution

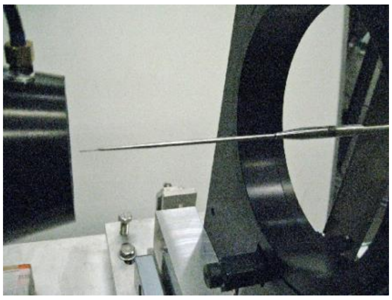

Fig. 3 Photograph of total pressure tube (measurement only total pressure)

Traverse device

A traverse device is used to measure the flow velocity distribution in a plane perpendicular to the axis of the jet from the nozzle exit. The traverse device has two degrees of freedom suitable to measure axi-symetric flow field as shown in Fig.2, that is, it has a mechanism of rotation as well as a mechanism of linear motion along a diameter. They are driven by precise stepping motors, with resolutions of about 0.002 mm for the linear motion about 0.00192 degree for the rotation.

Velocity field measurement using a total pressure tube

A total pressure was used to investigate the jet flow field from the nozzle exit. Its inner and outer diameters are 0.6 mm and 1.0 mm, respectively. The total pressure tube was installed in the traverse device as shown in Fig.3. The flow velocity is calculated by

$$u = K\sqrt{\frac{2\Delta P}{\rho}} \qquad (1)$$

Here, ΔP is the pressure difference between the static pressure of conversion nozzle near the exit plane and the total pressure of the total pressure tube. ρ is the air density at the conversion nozzle. K is the coefficient of total pressure tube, however, K=1 is assumed for the preliminary measurements described in this paper.

Averaged air velocity U_0 is also calculated from the volumetric flowrate at the nozzle exit

$$U_0 = Q_{nzl}/(\pi R^2) \qquad (2)$$

where Q_{nzl} is the converted volume flowrate from the mass flowrate measured by the nozzle chamber using the pressure and temperature measured as in Fig. 4. R is 30 mm.

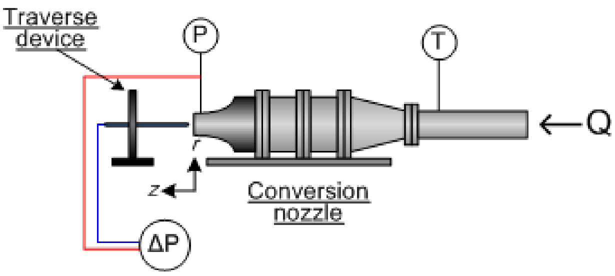

Fig.4 Experimental set-up around the conversion nozzle

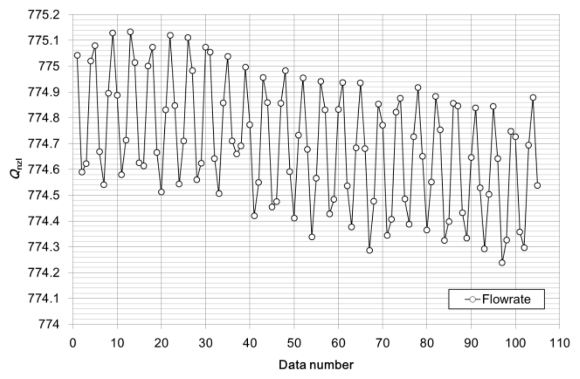

Fig.5 Fluctuation of generated flowrate

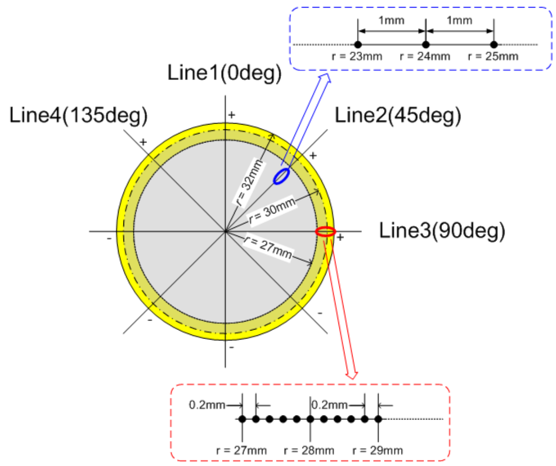

Fig. 6 Measurement point at the exit plane of the conversion nozzle

Stability of generated flowrates

Fig.5 shows one example of the fluctuation of volumetric flowrate at the conversion nozzle using the closed-loop calibration facility, when it is about 774.7[m^3/h]. The standard deviation of generated flowrates is about 0.03% throughout this paper. Therefore, the generated volumetric flowrate at the conversion nozzle is very stable.

Measuring location

The measuring locations are shown in Fig. 6. The tip of the total pressure tube is settled on a plane at an appointed location. The measurement was performed along the four lines shown in Fig. 6, which have an angle of 45 degree from each other on the measuring plane. The intervals of the measuring points along the radius were 1mm from *r*=0 mm to *r*=27 mm as shown in blue circle of Fig.6 and 0.2 mm from *r*=27 mm to *r*=32 mm as shown in red circle of Fig.6. Although the diameter of the nozzle exit is 60 mm, the measurements were performed up to *r*=32 mm in order to evaluate the influence of suction of air from outside the conversion nozzle.

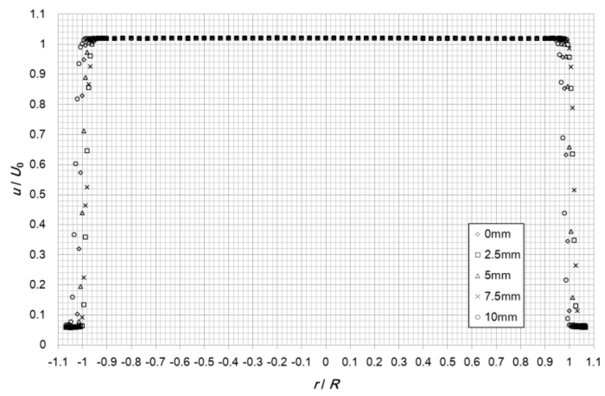

Fig. 7 Non-dimensional velocity profile at the cross-section (z=0, 2.5, 5, 7.5 and 10mm)

Results and Discussions

The axis of the jet blowout from the nozzle is defined as z-axis in the followings with its origin at the nozzle exit plane and its direction to the downstream of the flow.

Determination of z of the measuring plane

Non-dimensional flow velocity u/U_0 at *z*=0 mm, 2.5 mm, 5 mm, 7.5 mm and 10 mm are superimposed in Fig. 7 that shows that the velocity profile is almost constant in the region of $|r/R| \leq 0.9$ regardless of *z*. The velocity at the edge of the jet decreased rapidly and some scattering is observed depending on *z* but it was concluded that the scattering was caused by the scattering of the location of the rotation center of the traverse unit. When *r* is adequately shifted, there observed no significant difference between the velocity profiles at *z*=0~7.5 mm, therefore, *z*=5 mm was chosen as the default measuring plane in the followings. The residue of the total pressure at $|r/R| > 1$ will be decreased when the static pressure measurement is introduced.

Velocity profiles

The velocity profiles measured at the air speeds of ca. 39 m/s, 48 m/s and 76 m/s are shown in Figs 8~10. All the profiles have a constant velocity at $|r/R| \leq 0.9$. Scattering is again observed at the edge of the jet, but it should be mainly caused by the scattering of the rotation center of the traverse unit. The traverse unit is now being improved to set the rotation center exactly on z-axis at any *z*.

Comparison of the flow velocity obtained from the total pressure tube and the nozzle chamber are shown in Fig. 11.

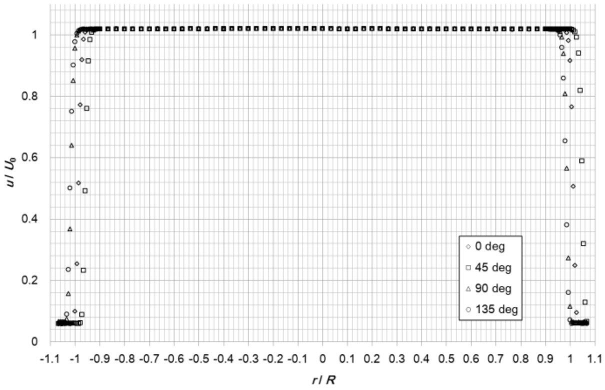

Fig.8 Non-dimensional velocity distribution (average velocity 39m/s)

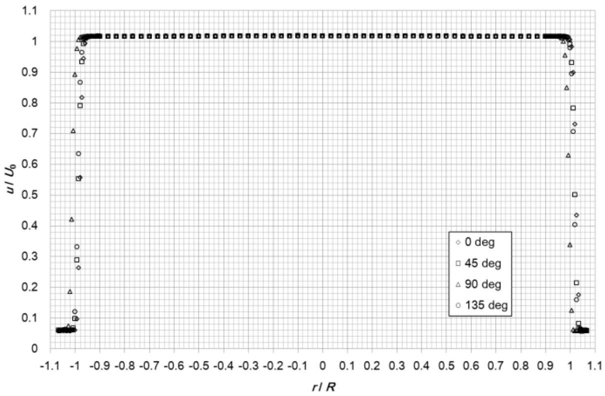

Fig.9 Non-dimensional velocity distribution (average velocity 48m/s)

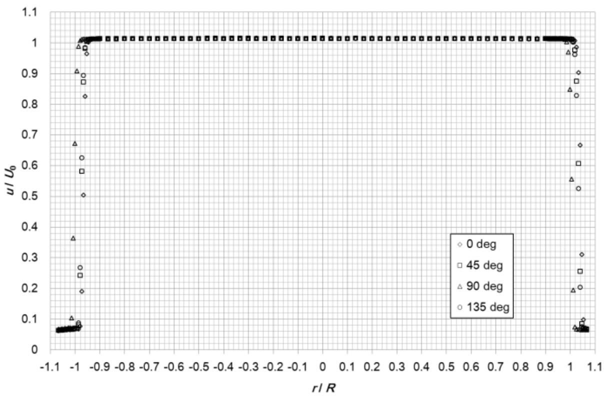

Fig.10 Non-dimensional velocity distribution (average velocity 76m/s)

There are a few % difference observed and it will be decreased when the static pressure measurement is introduced. The velocity distribution is now being integrated in the measuring plane to be compared with the volumetric flowrate at the conversion nozzle exit.

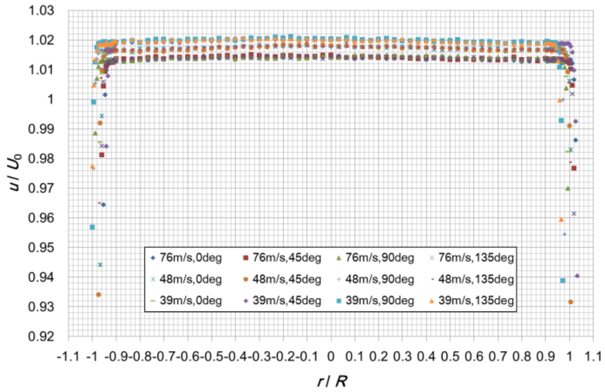

Fig.11 Non-dimensional velocity distribution (magnified and combined Figs 8~10)

Conclusion

Outline of the newly developing high air speed standard system in Japan is introduced. The system can generate air speed over 90 m/s. It uses a flowrate generated by an air flowrate standard system and convert it to the air speed using a conversion nozzle by measuring its velocity profile. As a preliminary measurement, some flow velocity profiles of the jet from the conversion nozzle at various conditions were measured and it is confirmed that the jet has a good enough top-hat profiled flow field. There was inaccuracy observed that affects the measurement seriously when locating the traverse unit, so it is now being improved. Static pressure measurement and hot-wire measurement are also being introduced soon, then the flow profile will be integrated into flowrate to be compared with the reference flowrate. The established air speed value will be transferred to an Eiffel type wind tunnel with the exit plane of 100 mm diameter that is already completed.

References

[1] A. Pope and J. J. Harper, Low-Speed Wind Tunnel Testing, John Wiley & Sons, Inc., 1966

[2] Y. Terao etc., Final Report on the CIPM Air Speed Key Comparison (CCM.FF-K3), 2007

[3] BIPM, CMCs Database, http://kcdb.bipm.org/appendixc/

[4] M. Ishibashi and T. Morioka, The renewed airflow standard system in Japan for 5–1000 m^3/h, Flow Measurement and Instrumentation, Vol.17, pp.153-161, 2006