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CHARACTERIZATION OF LOW TURBULENCE WIND TUNNEL

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Abstract: Wind tunnels with uniform velocity profiles and low turbulence are used to calibrate air velocity sensors such as anemometers and Pitot tubes among others. These wind velocity sensors are used in cases such as, for example, eolic turbines towers, meteorological stations, hospitals, etc. To make calibrations with high precision and accuracy it is necessary a wind tunnel with low turbulence (less than 0.4%) and uniform velocity profile in the test section. This study presents a characterization of the low turbulence wind tunnel of the Anemometry Laboratory of IPT (Institute for Technological Research), in which the calibrations are done in the discharge of the wind tunnel and the working range is from 2 m/s up to 40 m/s. A turbulence intensity less than 0.4% and a mean velocity variation of ± 0.2 % was obtained.

Keywords: wind tunnel, anemometry, turbulence.

1. INTRODUCTION

The calibration of air velocity sensors are preferably done in wind tunnels with uniform velocity profile and low turbulence intensity, usually lower than 0.4 %. The wind tunnel of the Anemometry Laboratory of IPT, illustrated in Fig. 1, was designed with these criteria in mind. Some kinds of air velocity sensor are illustrated in ANNEX A.

This wind tunnel has a flow conditioning section followed by a straight section 2 m long so that the flow can develop and stabilize. The contraction has an area ratio of 16:1 and the test section is 500 mm x 500 mm. The calibrations are conducted on the wind tunnel discharge.

Fig. 1. Wind Tunnel of IPT for anemometer and Pitot tubes calibration.

Previous testings were carried on this wind tunnel to compare anemometry techniques [1]. In these tests, the velocity profile was also measured in the test section of the wind tunnel.

This paper presents a complementary study to the previous one with the sole objective of characterizing the flow in the test section. The velocity profile in the test section was measured for flows with 10 and 20 m/s using static Pitot tubes. The turbulence intensity was measured between 2 up to 20 m/s using hot-wire anemometry (CTA – constant temperature anemometry).

2. METHODS

2.1 Measurement of Velocity Profile

To measure the velocity profile, the wind tunnel's test section was divided in 49 subsections (7 rows and 7 columns). In the central subsection, a static Pitot tube was kept fixed. The profile was measured from the difference of total pressure of the fixed Pitot tube to the measurement of a second identical static Pitot tube positioned in each of the remaining 48 subsections. In Figure 2 is shown this configuration.

Fig. 2. Wind Tunnel Test section of IPT. Two static Pitot tube were used to measure the velocity profile.

The total pressure difference of the two Pitot tubes were measured with a capacitive pressure transducer with 0.1 Pa of resolution.

The measurement of total pressure difference was chosen because it presents the lowest uncertainty. This kind of profile mapping takes a long time, in this study, close to 3 hours. During this large time interval, the wind tunnel velocity might change due to temperature increase of the flow and changes in electric motor performance. If every velocity point was measured directly, this change in wind tunnel velocity could be larger than differences in velocity profile (during calibrations, these variations are considered when calculating the uncertainty and each calibration point takes only a few minutes). Since only the differences in total pressure are measured, any variation in wind tunnel velocity is canceled out (both Pitot tubes are measuring under similar conditions). Another side benefit of this method is that lower pressure differences are measured, with an average pressure difference of around 0 Pa and an accurate low pressure differential transducer can be used.

The 10 m/s reference velocity in the test section was chosen since this velocity is required by the cup anemometer calibration procedure MEASNET [2]. Velocity profile mapping at wind tunnel reference velocity of 20 m/s was also conducted so results could be compared and this velocity is important in the usual calibrations conducted at the Anemometry Laboratory.

2.2 Measurement of Turbulence Intensity

Turbulence intensity was measured using a constant temperature anemometer (CTA) positioned at the center of the wind tunnel (see Figure 3). Turbulence intensity is equivalent to the ratio of the standard deviation of mean velocity to mean velocity (in percentage).

Fig. 3. Hot-wire anemometer (CTA) and static Pitot tube at the Wind Tunnel Test section of IPT.

This hot-wire anemometer was previously calibrated between 1 to 20 m/s, the same velocity range of this study. Each work wind tunnel velocity was measured by a static Pitot tube and compared with the hot-wire anemometer measurement to verify its calibration.

3. RESULTS

Figure 4 shows the velocity profile at the test section for an average velocity of 10 m/s. The color contour map indicates the variation in air speed in relation to the center velocity (fixed Pitot tube) in percentage.

The Figure 4 shows that the average velocity variation is within ±0.2 % of the center velocity. Extreme cases, above ±0.5 %) are located near the wind tunnel walls, as expected.

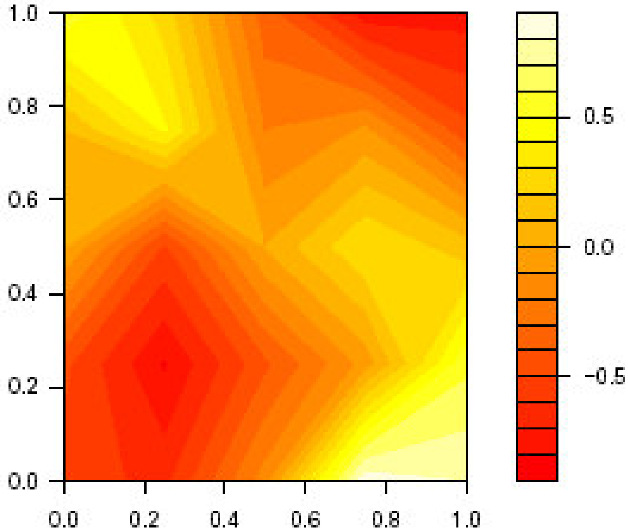

Fig. 4. At 10 m/s velocity map from wind tunnel test section (500 mm x 500 mm). The color map is shown in percents.

Figure 5 shows the velocity differences observed for a wind tunnel velocity of 20 m/s.

The results are very similar to those obtained for 10 m/s. The average variation is also around ±0.2 % with peak values near the walls a little above ±0.5 %.

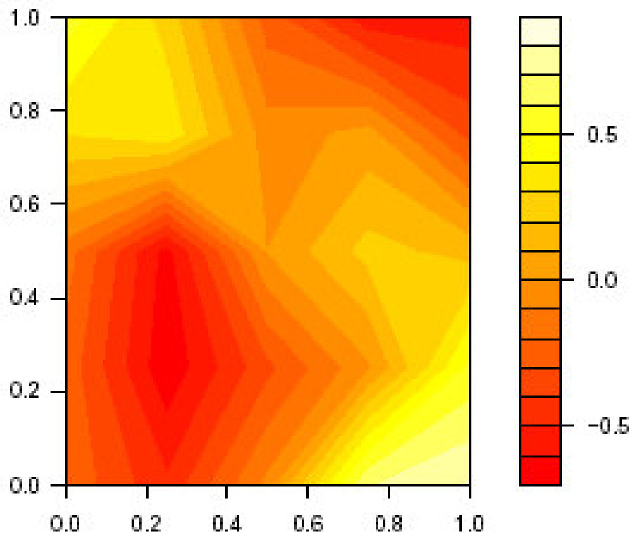

Fig. 5. At 20 m/s velocity map from wind tunnel test section (500 mm x 500 mm). The color map is shown in percents.

The turbulence intensities obtained are illustrated in Table 1, and Figure 6 illustrates a typical signal sample acquired by an hot-wire CTA.

Table 1. Turbulence Intensity of IPT Anemometry Wind Tunnel.

Velocity (m/s)	Turbuence intensity (%)	Turbulence intensity uncertainty (%)
2.5	0.32	0.02
5.0	0.38	0.02
10.0	0.35	0.03
15.0	0.44	0.03
20.0	0.45	0.03

Notice, in Table 1 are illustrated the mean velocities of acquisitions.

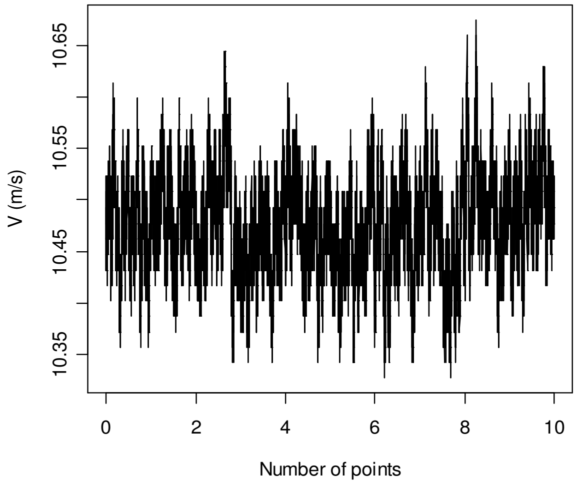

Fig. 6. Typical signal sample acquired using a hot-wire CTA. This sample was acquired at mean velocity 10 m/s.

This wind tunnel is apt to calibrate velocity sensors whose projected area is not above 10 % of the test section. The calibration range in this wind tunnel is from 2 m/s up to 40 m/s. For speeds of 10 m/s and up the velocity variation is in average ±0.2% in the central region of the wind tunnel. For lower velocities, the velocity profile should be further investigated. The mean turbulence intensity is inferior to 0.4%.

3. CONCLUSION

The velocity profile measurement of this study has shown that the wind tunnel of the Anemometry Laboratory from IPT satisfies the minimum requirements for anemometer calibration (within the scope of MEASNET [2]).

The velocity variation throughout the test section (away from the walls is below ±0.2 % and mean turbulence intensity for velocities range between 2.5 to 20 m/s is below 0.4 %.

Nowadays this wind tunnel is used for calibrations from 2 m/s up to 40 m/s. For low velocities (2 – 10 m/s) the velocity profiles should be further investigated but the results should not differ very much.

There is a large interest in industry (mainly ventilation applications) for calibration of very low velocity sensors (2 m/s down to 0.1 m/s). The wind tunnel was not originally designed to operate in this condition and therefore the velocity profile of very low velocities will be investigated to determine whether the wind tunnel can be used to calibrate sensors for this velocity range and whether any modifications to wind tunnel are necessary.

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[2] *MEASNET* - Cup Anemometer Calibration Procedure - september 1997

ANNEX A

Some kinds of anemometer and Pitot tubes calibrated in IPT Wind Tunnel are shown in the following figures.

Figure A1 shows a typical vane anemometer.

Fig. A1. Typical vane anemometer positioned at the wind tunnel test section.

Figure A2 shows a hot-film (or hot-wire) anemometer

Fig. A2. Hot-film anemometer to be calibrated.

Figure A3 shows a cup anemoter, frequentely used in eolic generators towers. This cup anemometers are calibrated by procedure of MEASNET [2].

Fig. A3. Cup anemometer positioned at the discharge of the wind tunnel.

Figure A4 shows a 3D sonic anemometer

Fig. A4. A 3D sonic anemometer.

Figure A5 shows a static Pitot tube in calibration process.

Fig. A5.Pitot tube in calibration process.

And Figure A6 shows a Cole Pitot tube, calibrated in air, but to be used in water flow measurements. This calibration is done using Reynolds number similarity.

Fig. A6. A Cole Pitot tube calibrated in air.