Effects of screens set characteristics on the flow field in a wind tunnel

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Abstract. Wind tunnels have broad range of applications, and although there are common elements among the different types of tunnels, the layout and configuration of each facility will depend on its particular purpose. The flow conditioners section is a common component for all tunnels, and frequently contains flow straighteners and screens [1]. The role of screens is to minimize non uniformities or turbulence level on the flow field. In this work, the development and characteristics of the vertical velocity profile along an atmospheric wind tunnel length were evaluated. By using such data as initial reference, the effects, on the flow, when screens set is inserted on it were analyzed, in order to identify which changes could be done in the wind tunnel configuration to improve the characteristics of the flow field. Such atmospheric wind tunnel is a facility which belongs to the Brazilian National Metrology Institute INMETRO.

1. Introduction
A wind tunnel is a facility designed to produce a regular and controlled stream of air in order to determine experimentally the flow conditions and to measure stress distribution in model testing. Atmospheric wind tunnels are used as important tool to evaluate various studies in the engineering field, such as small-scale testing in aircraft and cars models, study of boundary layers, pollutant dispersion investigations, simulation of atmospheric layers and other applications [2,3]. In order to perform the experiments aforementioned, the flow quality in the wind tunnel is necessary, as for example, a uniform and steady velocity profile at the wind tunnel entrance, the turbulence intensity reduction in test section etc. The last one is made by using screens and honeycombs. The screens reduces axial turbulence more than lateral turbulence, while honeycombs reduce lateral turbulence more than axial turbulence.

Wind tunnels screens are composed by thin wires interwoven to form square or rectangular meshes. Mehta [4] studied the effect of screen material in the flow quality and discovered significant differences between plastic and metal screens due to the fact that the weaving properties and elastic modulus of the fibers are distinct. Karnik and Tavoularis [5] discussed the influence of mesh size and spacing screens on the reduction of flow non-uniformities, considering a same wire solidity and shape, for a uniformly sheared flow.

In metrology area, several studies are concerned to characterization of the flow for velocity measurement instruments calibration and fluid dynamics investigations [6-8]. The National Institute of Metrology, Quality and Technology (Inmetro) from Brazil designed and constructed an atmospheric wind tunnel for research and technological applications. Based on previous
results from this wind tunnel characterization, the need of flow quality improvement inside the tunnel was identified. Thus, the main goal of the present work is to investigate the effect in non-uniformity of the flow field by using screens in the flow. The measurement techniques employed to measure flow parameters such as turbulent intensity and average velocity were hot-wire anemometry and ultrasonic anemometry.

2. Experimental apparatus and procedures

2.1. Wind tunnel description
The atmospheric wind tunnel from Inmetro (Figure 1) is a low speed and high turbulence intensity level facility. It is an open-circuit tunnel with 10 m long, divided in 5 modules of 2 m length each one, (1.0 × 1.0 m²) closed test section.

The flow speed is controlled by a frequency inverter connected to a fan (9 kW) and the maximum mean velocity is about 10 m/s. Air cross a set of screens, a diffuser (ratio 1:2) and a honeycomb before entering into the settling section.

![Figure 1. The atmospheric wind tunnel of Inmetro.](image)

2.2. Hot-wire anemometry
The hot-wire anemometry is an intrusive technique used to measure flow parameters such as turbulent intensity and averaged velocity by sensing the changes in heat transfer from a small, electrically heated sensor exposed to the fluid motion [9]. There are two categories for hot-wire anemometers, i.e., single and x-probe. Single wire probes, where the wire is oriented normal to the mean flow direction, are used to measure the velocity component in the mean flow direction. The crossed wire probes or x-probes, consisting of two wires arranged in an x-configuration, are employed to measure both stream-wise and cross-flow velocity components simultaneously [10].

In this wind tunnel characterization, the hot-wire anemometer used was a single wire probe (55P11) with the software Streamware™, both from Dantec Dynamics. A Constant Temperature Anemometry (CTA) bridge was used to acquire the data, which were processed by Excel™. The Dantec Dynamics Hot Wire Calibrator was used before running measurements in each position in the tunnel. The number of samples for each point measured was 65536, under the sampling rate of 10 kHz.

2.3. Ultrasonic anemometry
The anemometer used to measure the mean velocity was a 3D ultrasonic anemometer (Kaijo Sonic, model DA-600), with velocity range from 0 m/s to 20 m/s and resolution of 0.005 m/s, calibrated and traceable to the National Metrology Institute of Japan (NMIJ).
2.4. Experimental Procedure

In the previous work [6], the wind tunnel characterization consisted of velocity profiles determination in 5 test sections (see Figure 2) along the wind tunnel length, by using Pitot Tube. Six different levels of mean velocities for the wind were tested and all the measurements were made on vertical lines which crossed the symmetry axis of the tunnel. After measuring such velocity profiles it was observed high non-uniformity of it. Then, seeking out the uniformity of the flow field, changes of the ceiling inclination were made. The ceiling was tilted from the first module entrance up to the end of the third module. This resulted in 1.9 degrees of inclination along 6 meters of the tunnel length.

Based on the aforementioned results, in the present work hot wire anemometer technique was employed to measure instantaneous velocities. So, the turbulence intensity was also calculated in a region where the velocity profile was uniform (or almost).

Firstly, the measurements were done without the screens set in the end of the section III (Figure 2a) and in the end of the section V (Figure 2b), both in the symmetry axis. Seven vertical positions were analyzed and, for each position, six different levels of mean velocities for the wind were settled, as done in the tests aforementioned [6].

![Figure 2](image_url)

**Figure 2.** Position of the measuring instrument in wind tunnel (a) in the end of the section III, (b) in the end of the section V.

The second step included the measurements in the middle of the section V (Figure 3), in the symmetry axis of the cross section, by using hot-wire anemometer with and without screens set. Due to the screens size, five vertical positions were evaluated in both experimental conditions aforesaid. The screens set is composed by two stainless steel screens as described in Table 1.

![Figure 3](image_url)

**Figure 3.** Position of the measuring instrument in wind tunnel with and without screens set.

The screens set were mounted with an interspace equal to 100 mm. The space between the anemometer and the screens set was also 100 mm, related to ten times the mesh size, related to screen II. The position of the anemometer was the same presented in the Figure 3. The Figure 4 shows the screens assembly inside the wind tunnel.

The last step consisted of measurements in the wind tunnel with the screens set by using ultrasonic anemometer. The most representative results are presented in the next topic.
Table 1. Details of screens samples

| Screen | Wire diameter (mm) | Mesh size (mm) |
|--------|-------------------|---------------|
| I      | 1.65              | 8.51          |
| II     | 2.10              | 10.59         |

Figure 4. Screens set inside the wind tunnel.

3. Results and Discussion

The results obtained to the velocity profile in the symmetry axis to the sections III and V and its respective turbulence intensities are showed in the Figures 5 and 6.

Figure 5. Velocity profile using hot wire anemometer positioned in the section III, as shown in Figure 2a (solid line) and in the section V, as shown in Figure 2b (dashed line).
Analyzing the results above-mentioned, the velocity profiles on the vertical plane of symmetry along both tunnel sections were very similar. Nevertheless, the turbulence intensity showed distinct behaviors. In the section III, the turbulence intensity varied from 1.5% to 5% and in the section V, this range was from 1.5% to 6%. Besides, for both sections evaluated, there is a range of mean velocity of the wind tunnel (1 to 3.5 m/s) on which is possible to introduce appropriate designed devices for atmospheric boundary layer behavior reproduction, without diminishing considerable length of the test section, since in such velocity range the velocity profile is almost uniform. However, for higher mean velocities range than that, limitations can derive due to the short length of test section available for flow development inside the tunnel.

Based on the similarity between the velocity profiles obtained in the tunnel sections analyzed previously, the middle of the last section was chosen to evaluate the effect of the screens set as presented in Figure 7. The Figure 8 shows the effects on turbulence intensities due to screens.

**Figure 6.** Turbulence intensity for the hot wire anemometer positioned in the section III (left) and the section V (right).

**Figure 7.** Velocity profile using hot wire anemometer positioned in the section V without screens set (solid line) and with screens set (dashed line).
Analyzing the results above-mentioned, the velocity profiles on the vertical plane of symmetry were improved significantly with the addition of screens set. It means that screens set were effective not only in reducing the mean velocity, in the region of the screens set, but also in smoothing the velocity non-uniformity. The turbulence intensity (with and without screens) showed very distinct behaviors. The turbulence intensities became higher by using screens set, varying from 6.8% to 8.2%, while without screens this range was from 1.0% to 5.6%. However, turbulence level dispersion was diminished due to screens presence.

To validate the experiments which were carried out using hot wire anemometer, ultrasonic anemometer was employed, because it is traceable to the national measurement standards from NMLJ, as aforementioned. The Figure 9 presents the results obtained in the wind tunnel with screens set by employing both anemometers.

According the Figure 9, the mean velocity obtained by ultrasonic anemometer showed a slight increase when compared with the results from hot wire anemometer. In addition, the velocity profiles were very similar for both anemometers including non-uniformity for high velocities.

In relation to measurements using hot-wire anemometer, it was identified some uncertainties sources due to the hot-wire anemometer probe positioning, calibration equipment and method, frequency response, electrical noise, data acquisition and climatic conditions (temperature, pressure and humidity) [11-12]. Thus, it is necessary to investigate more deeply the contribution of each uncertainty source in the results obtained.
3.1. Some considerations about uncertainty of hot-wire anemometers

This topic will present a brief discussion about uncertainties associated with temperature variations from calibration to experiment, which is one of the major uncertainty source [11-13].

Firstly, it is necessary to correct the voltages $E_a$ for temperature variations during calibration as shown in (1):

$$E_{corr} = \left( \frac{T_w - T_0}{T_w - T_a} \right)^{0.5} E_a$$

where $E_a$ = acquired voltage; $T_w$ = sensor hot temperature; $T_0$ = ambient reference temperature related to the last overheat set-up before calibration; $T_a$ = ambient temperature during acquisition.

Secondly, a 4th order polynomial is created (2), which relates the velocity to the corrected voltage read by the acquisition system:

$$v = C_0 + C_1 E_{corr} + C_2 E_{corr}^2 + C_3 E_{corr}^3 + C_4 E_{corr}^4$$

where $C_0$ to $C_4$ are the calibration constants and $v$ is the velocity. Thus, the corrected velocity, $v_{corr}$, is a function such that (3):

$$v_{corr} = f(v, T_w, T_0, T_a)$$

Since $T_0$ and $T_w$ are constants in the partial derivative $\partial v_{corr}/\partial T_a$, $v_{corr}$ can be expressed as (4):

$$v_{corr} = f(v, T_a)$$

To determine $v_{corr}$ as function of $v$, the suitable polynomial root from (2) is found and then applied in (1), such that (5):

$$E_{corr} = f(v)$$

Then, replacing (5) in (1), the corrected velocity can be found as function of the uncorrected velocity (6):

$$v_{corr} = f(v)$$

With (6), one can calculate the influence of temperature to the velocity uncertainty, which is presented in (7):

$$u(v_{T_a}) = \frac{dv_{corr}}{dT_a} u(T_a)$$

Figure 10 shows the velocities uncertainties due to the temperature uncertainty, considering:

$T_0 - T_a = 5 ^\circ C$,

$u(Ta) = 0.05 ^\circ C$
As can be seen in the Figure 10, the relative velocity uncertainty decreases as velocity increases, as expected. It is important to notice that this is only one of the uncertainty sources; the full model for calculating the uncertainty may have up to 9 terms, including the calibrator certificate, which have a typical value of uncertainty of 1%.

4. Conclusion
In this work, the velocity profile and the turbulence intensity of the tunnel were investigated in the vertical symmetry axis of the cross section. The results obtained without the screens set indicated that for low average speed of the flow in the wind tunnel, the velocity profile on the vertical plane tends to be uniform. Nevertheless, for high velocities, non-uniformities in the velocity profile were noted. The addition of screens set reduced the mean velocity and also diminished the non-uniformities.

Although the turbulence intensity was higher with the screens set addition, it became more uniform. So, it is possible to conclude that the screens set employed in this work contributed significantly to improve not only the velocity profile but also the turbulence intensity dispersion. It is suggested that others configurations of screens must be assessed.

In this work, since the atmospheric wind tunnel from Inmetro is mounted and operational, the examination of its flow characteristics deals with two important purposes related to the Scientific Metrology activities in fluid dynamics area, which are: the effort for refinement of experimental procedures in order to minimize measurement uncertainties and the endeavor to add relevant and reliable experimental data on complex fluid flow to the literature, in order to contribute to knowledge advances.

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References
[1] Barlow J B, Jr. Rae W H and Pope A 1999 Low speed wind tunnel. 3th Ed. (New York: John Wiley and Sons, Inc)
[2] Stull, R B 1988 An introduction to boundary layer meteorology (The Netherlands: Kluwer Academic Publishers)
[3] Kulkarni V, Sahoo N and Chavan S D 2011 J. Wind. Eng. Ind. Aerodyn. 99 (1) 37
[4] Mehta R D 1985 AIAA Journal 23 (9)1335
[5] Karnik U and Tavoularis S 1987 Exp. Fluids 5 (5) 247
[6] Farias M H, Santos A M, Souza D B, Ferreira, L L R, Massari P de L, Massari P L, Garcia D A and Costa F O 2014 Anais Proc. - 3rd Cimmec art. 127620
[7] Nader G, Santos C, Jabardo P J S, Cardoso M, Taira N M and Pereira M T 2006 XVIII IMEKO World Congress
[8] Piccato A, Spazzini P G and Malvano R 2009 7th ISFFM
[9] Erm L P 2000 Calibrations of the flow in the test section of the low-speed wind tunnel at AMRL (DSTO Aeronautical and Maritime Research Laboratory)
[10] Manshadi M D 2011 The importance of turbulence in assessment of wind tunnel flow quality, wind tunnels and experimental fluid dynamic research (Available from: www.intechopen.com/book/wind-tunnels-and-experimental-fluid-dynamics-research-the-importance-of-turbulence-reduction-in-assessment-of-wind-tunnelflow-quality)
[11] Bruun H H 2002 Hot-wire anemometry principles and signal analysis. 1st Ed. (New York:Oxford University Press)
[12] Jørgensen F E 2002 to measure turbulence with hot-wire anemometers a practical guide. (Denmark: Dantec Dynamics)
[13] Yavuzkurt S 1984 J.Fluids Eng. 106 181