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

A M Santos, D B Souza, F O Costa, M H Farias, S Araújo, Y B Zanirath

National Institute of Metrology, Quality and Technology – Inmetro

E-mail: dinam@inmetro.gov.br

Abstract: Wind tunnels have broad range of applications. Although there are common elements among the different tunnels, the layout and configuration of each facility will depend on its particular purpose. The flow conditioners section is a component for all tunnels and generally contains flow straighteners and screens. The screens are employed to minimize non uniformities or turbulence levels on the flow field. The aim of this study is evaluate the effects when screens sets are inserted into the flow, in order to identify which changes could be done in the wind tunnel configuration to improve the characteristics of the flow field.

Keywords: wind tunnel, screens, turbulence intensity, hot wire anemometry, ultrasonic anemometry.

1. INTRODUCTION

Atmospheric wind tunnels are employed as important tools 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 [1,2]. In order to perform the experiments aforementioned, some criteria of the flow in the wind tunnel are necessary, as for example, a uniform and steady velocity profile at the wind tunnel entrance, turbulence intensity reduction in test section, among others. In the metrology field, several studies are concerned to the characterization of the flow for velocity measurement instruments calibration and fluid dynamics investigations [3-5]. The National Institute of Metrology, Quality and Technology (Inmetro) from Brazil designed and built an atmospheric wind tunnel for research and technological application. Based on previous results from this wind tunnel characterization, the need of flow quality improvement inside the tunnel was investigated. 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 (1.0 × 1.0 m^2) 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.

2.2 Hot-wire anemometry

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 runing 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 $m{\cdot}s^{-1}$ to 20 $m{\cdot}s^{-1}$ and resolution of 0.005 $m{\cdot}s^{-1}$, calibrated and traceable by National Metrology Institute of Japan (NMIJ).

2.4 Experimental procedure

The wind tunnel characterization consisted of velocity profiles determination in the middle of the section V (figure 2), in the symmetry axis of the cross section.

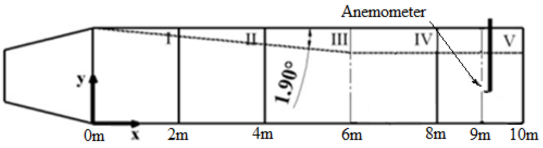

Figure 2 – Position of the measuring instrument in wind tunnel.

Firstly, the measurements were made by using hot-wire anemometer without the screens set. Five vertical positions were analyzed and for each position, six different levels of mean velocities for the wind were tested.

The second step included the use of screens set composed by two stainless steel screens as described in table 1.

Table 1. Details of screens samples.

Screen	Wire diamenter (mm)	Mesh lenght (mm)
I	1,65	8,51
II	2,1	10,59

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 length size, related to screen II. The position of the anemometer was the same presented in the figure 2. The figure 3 shows the screens assembly inside the wind tunnel.

Figure 3 – Position of the measuring instrument in wind tunnel.

The last step consisted of measurements in the wind tunnel with the screens set by using hot-wire anemometer and ultrasonic anemometer.

The most representative results are presented in the next topic.

3. RESULTS AND DISCUSSION

The results obtained to the velocity profile in the symmetry axis of the section V and its respective turbulence intensities, by using hot-wire anemometry, are showed in figures 4 and 5, respectively.

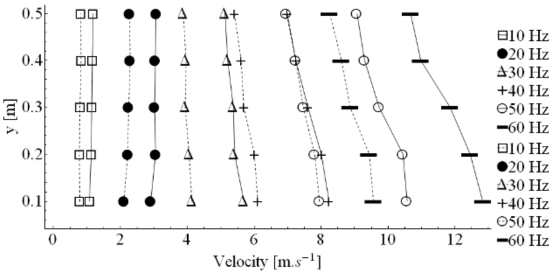

Figure 4 – Velocity profile using hot wire anemometer positioned in the section V without screens set (straight line) and with screens set (dashed line).

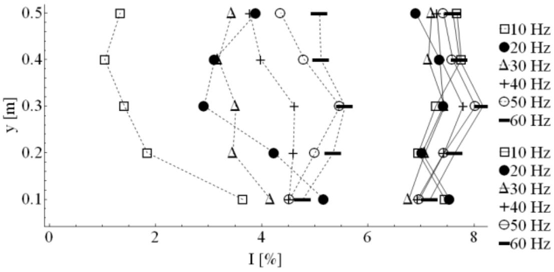

Figure 5 – Turbulence intensity for the hot wire anemometer positioned in the section V without screens set (straight line) and with screens set (dashed line).

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 decreasing 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%.

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 NMIJ, as aforementioned. The figure 6 presents the results obtained in the wind tunnel with screens set by employing both anemometers.

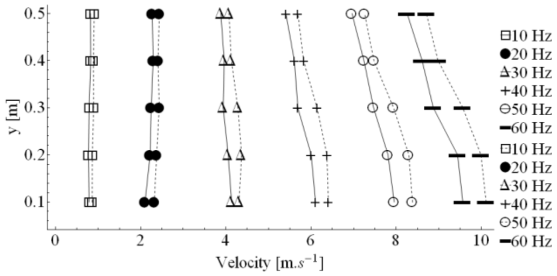

Figure 6 – Velocity profile with screens set using hot wire anemometer (straight line) and ultrasonic anemometer (dashed line).

According the figure 6, 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) [6-7]. 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 [6-8].

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

$$\boldsymbol{E_{corr}} = {\frac{\boldsymbol{T_w - T_0}}{\boldsymbol{T_w - T_a}}}^{\boldsymbol{0.5}} \boldsymbol{.\, E_a} \qquad (1)$$

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:

$$\boldsymbol{v = C_0 + C_1 . E_{corr} + C_2 . {E_{corr}}^2 +}$$
$$\boldsymbol{C_3 . {E_{corr}}^3 + C_4 . {E_{corr}}^4} \qquad (2)$$

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):

$$\boldsymbol{v_{corr} = f\ \ v, T_w, T_0, T_a} \qquad (3)$$

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

$$\boldsymbol{v_{corr} = f\ \ v, T_a} \qquad (4)$$

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

$$\boldsymbol{E_{corr} = f\ \ v} \qquad (5)$$

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

$$\boldsymbol{v_{corr} = f\ \ v} \qquad (6)$$

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

$$\boldsymbol{u\ \ v_{T_a}\ = \frac{dv_{corr}}{dT_a} . u\ \ T_a} \qquad (7)$$

Figure 7 shows the velocities uncertainties due to the temperature uncertainty, considering:

$T_0 - T_a$ = 5 °C

$u(T_a)$ = 0,05 °C

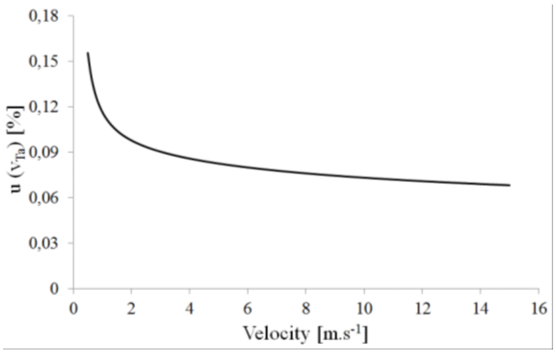

Figure 7 – Velocities uncertainties due to the temperature uncertainties versus velocity.

As can be seen in the figure 7, 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 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. 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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