# CHARACTERIZATION OF THE VELOCITY FIELD IN A DUCT OF 180° BY A MULTIHOLES PROBE

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***Abstract.*** *Over the years, the three-dimensional measurement of complexes and tridimensional flows has been consolidated with the use of optical techniques, such as PIV (Particle Image Velocimetry) and Laser Doppler Anemometry (LDA), however, these techniques have high costs of acquisition in compared to other techniques as hot wire anemometry and multi-hole pressure probes, making them inaccessible to many laboratories. In this work was used a low cost multi-hole pressure probes for the measurement of the velocity field in a curved section of 180 ° in a wind tunnel of low intensity turbulent. The main objectives of this study and analysis of use are two methods of calibration of multi-hole pressure probes, comparing their methodologies and results, the latter being presented in the form of non dimensional coefficients and velocity field. To make possible the implementation of this work and then to obtain their results, it was necessary to adopt a series of methodological tools for acquiring and processing the data collected in experiments, ranging from the creation of a method of collecting data of pressure, that was the generation of seven plans of measurements, where each plan contained fifteen stations for measuring, by the employment of a routine computer, which runs through double interpolations linear regressions, from the commercial code MATLAB in order to find, through the curves of calibration of the multi-hole pressure probe, data that is going serve as subsidies for obtaining the mean velocity vectors of the flow in each of the seven plans for measuring over the duct of 180° of the wind tunnel. This was an early work which consisted of a campaign of experimental tests with the multi-hole pressure probe aiming to check the feasibility of its use in an ongoing study on cyclonic flow.*

***Keywords****: multi holes probe, complex flow, velocity field, wind tunnel*

## 1. INTRODUCTION

The experimental data in many complex flow fields are commonly obtained through multi-hole pressure probes. These types of probes have long been used in various forms to measure velocity components and the local pressure field in three dimensional flows such as those encountered in turbo machines and around complex bodies. The application of these probes requires three dimensional calibration data. The probe can be operated in two ways, in both nulling and non-nulling mode.

Some calibration techniques of a five-hole probe are available in the literature. One of them is the most common method and it was proposed by Treaster and Yocum (1979). In their technique the probe is calibrated in a non-nulling mode or in a fixed position. The technique is simple but encounters singularity when is employed for large pitch or yaw angles. In their study, a 3.18 mm diameter prism-type sensor and a 3.81 mm diameter conical-type sensor were employed at Reynolds number based on tip diameter range from 2000 to 7000.

Pisasale and Amhed (2002) had considered a new method which is simple; of easy implementation and that it surpasses the singularity problem found in the traditional method considered by Treaster and Yocum. The method was tested using the data of calibration of a five holes pressure probe that had been obtained using a subsonic wind tunnel, with a test section of 18in x 18in and velocity of 15 m/s. The new procedure showed that the calibration curve can be extended successfully until angles of ±75º.

This paper describes the use of a five-hole pressure probe in obtaining properties of a three-dimensional flow produced by a curve-shaped (U) coupled to the wind tunnel. The discussion of the calibration methods, the results of the velocity field on the curve and a physical analysis of the problem, is presented.

## 2. EXPERIMENTAL APPARATUS AND PROCEDURES

A photo of the experimental apparatus is shown on Figure 1. The wind tunnel used to accomplish the probe calibration and obtain the data set is of open circuit, it has curved walls with square-shaped section of 0,30m x 0,15m, the air is supplied by a centrifugal fan which is controlled by a frequency controller and is located in the Laboratory of Fluid Mechanics of the Faculty of Mechanical Engineering at Federal University of Pará. The tunnel supplies an uniform flow at the entrance of the test section, and for this work, the velocity flow was fixed in 10m/s, which was established with a Pitot tube inserted into the flow. The pressure probe that was used in the present study is shown in Fig. 2. The pressure probe is constituted by five steel tubes of hypodermic needles with internal diameter of 0.5mm, external diameter of 0.9mm and 70,0 mm of length.

Figure 1. The wind tunnel.

For the accomplishment of the calibration in some pitch and yaw angles, the use of a mechanism was necessary to allow the support, the setting and the variation of the pressure probe tip in various angles. The mechanism used, as well as the pressure probe of five holes, were constructed by the technician of the laboratory. A photo of the mechanism that allows the movement of the pressure probe is shown in Fig. 3**.**

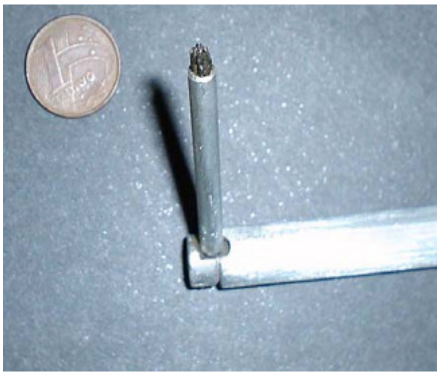

Figure 2. The five-holes pressure probe.

Figure 3. Mechanism of angle variation.

## 3. CALIBRATION PROCEDURE

The probe used in this work was a five-hole pressure probe; this type of configuration provides better sensitivity of the pressure probe in relation to the attainment of the data set. The principle for the attainment of the velocity field using anemometric pressure probes is based on the decomposition of the velocity vector, where the angles $\alpha$ (pitch angle) and $\beta$ (yaw angle) are the angles that define the velocity vector.

The calibration of this kind of probe can be carried out through the nulling or non-nulling mode of pressures. In the nulling mode a pressure balance during the use of the pressure probe is accomplish. The calibration procedure consists of the measurement of the total pressures in all the tubes that constitute the pressure probe. As they are five tubes it is necessary to get the pressure in each one of them: P1, P2, P3, P4 and P5. The pressure probe is fixed in the mechanism of angular variation and then is submerged into the wind tunnel. The exits of the tubes are connected independent one of the other through flexible tubes in a manometer.

The attainment of the pressure measures were carried out through the direct reading of the manometer. The amount of data that had been obtained from the reading is considered great since the angle variation is in the range of -15º up to 15º in the pitch plane, and -30º up to +30º in the yaw plane. For each variation five readings of pressure are obtained. Figure 4 presents a schematic drawing of the angle variation and the tip of the pressure probe.

This study investigated two calibration methods for multi hole pressure probes, which are the methods proposed by Treaster and Yocum (1979) and Pisasale and Ahmed (2002) in which are described the experimental procedure used for each method. For probes with the geometry that was used in this work, it is necessary to carried out calibrations due to its complex geometry and the changes occurring in its contour, separation of flow and viscous effects around the same, hence the need to obtain accurate data rather to characterize a highly three-dimensional flow.

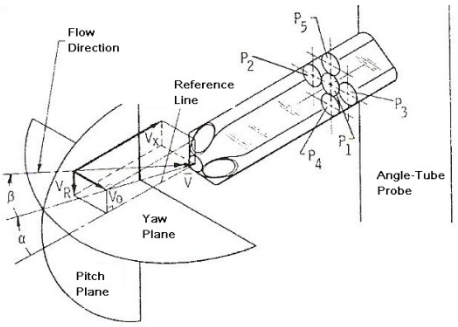


Figure 4. The pressure probe

### 3.1 Calibration Using the Method of Treaster and Yocum

The most usual method of calibration considered for Treaster and Yocum (1979) is sufficiently simple. The technique essentially consists in an adaptation of the calibration tradition of a five probes pressure probe, using it in a non-nulling mode. In this mode P1 is considered in the total pressure, and is considered the static pressure. Consequently the difference between P1 and static pressures represent the dynamic pressure which is used to obtain the calibration coefficients of pressure.

The four coefficients of calibration used by Treaster and Yocum are defined by the following expressions:

$$Cp_{yaw} = (p_2 - p_3)/(p_1 - \overline{p}) \tag{1}$$

$$Cp_{pitch} = (p_4 - p_5)/(p_1 - \overline{p}) \tag{2}$$

$$Cp_{total} = (p_1 - p_{total})/(p_1 - \overline{p}) \tag{3}$$

$$Cp_{static} = (\overline{p} - p_{static})/(p_1 - \overline{p}) \tag{4}$$

$$\overline{p} = (p_2 + p_3 + p_4 + p_5)/4 \tag{5}$$

$$\bar{V} = [(0{,}5/\rho)(\Delta P_1 - \Delta P_m)(1 + Cp_{static} - Cp_{total})] \tag{6}$$

### 3.2 Calibration Using the Method of Pisasale e Ahmed

The method proposed by Pisasale is basically to expand the range of calibration of a five holes probe for highly three-dimensional flows, due the methods employed are not suitable for a large range of calibration angles, as often occurred singularity, hence the need to use a method which would meet the calibration of the probe for a greater range of angles of deviation and direction.

The experimental procedure was conducted in a manner similar to the method of Treaster and Yocum, taking all care in carrying out measures to avoid singularities and extend the range of calibration for high angles of deviation and direction. The method developed by Pisasale uses a new way to find the adimensional coefficients calibration, which uses the following parameters:

$$N_y = \frac{p_1 - \overline{p}}{DEN} \tag{7}$$

$$DEN = p_1 - p_s + A_q \tag{8}$$

$$N_x = \frac{p_1 - \overline{p}}{\sqrt{(p_2 - p_3)^2 + (p_4 - p_5)^2}} \tag{9}$$

$$N_y^* = \frac{DEN}{\sqrt{(p_2 - p_3)^2 + (p_4 - p_5)^2}} \tag{10}$$

$$Cp_{yaw} = \frac{p_2 - p_3}{DEN} \tag{11}$$

$$Cp_{pitch} = \frac{p_4 - p_5}{DEN} \tag{12}$$

$$Cp_{static} = \frac{\overline{p} - p_5}{DEN} \tag{13}$$

$$Cp_{total} = \frac{p_1 - p_t}{DEN} \tag{14}$$

$$\bar{V} = \sqrt{\frac{2\Delta P}{\rho}} \tag{15}$$

# 4. RESULTS

The experimental results have been obtained establishing the initial velocity of 10 m/s in the entrance of the test section at the straight line. The measures had been obtained in seven stations of the wind tunnel; these stations had been defined as plans 1, 2, 3, 4, 5, 6 and 7 to assist in the experimental methodology and analysis of the behavior of the pressure throughout the curve. Figure 5 presents the localizations of each plan.

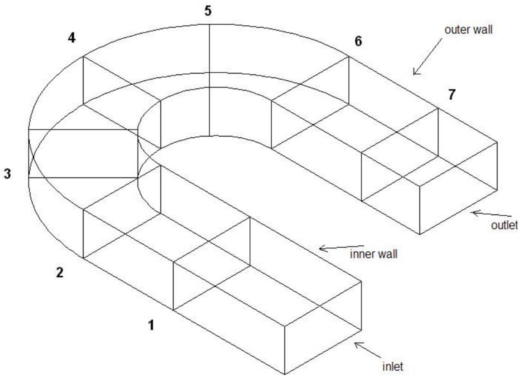


Figure 5 – Schematic draw of the seven planes on the curved channel.

The calibration procedure was led remaining a constant velocity of 10 m/s in the test section. A pressure tap in the test section was constructed to get the static pressure in the wall of the wind tunnel. The pressure probe was located where the velocity was maximum in the flow, and it was fixed through the device to change angles. The probe was set in an initial yaw angle (α) and the pitch angle was put into motion according to its increments, varying the pitch angle from -15° up to +15°, and the yaw angle of -30° direction up to +30°. The calibration procedure was repeated three times to verify the repeatability of the results.

The results of the calibration had been placed in terms of the nondimensional coefficients of pressure considered by both methods, which are functions of the flow angularity. The plot of the calibration data by Treaster and Yocum is presented in Fig. 6a-c and the calibration data by Pisasale and Ahmed in Fig 78a-e.

The calibration data for the probe used in this study and that used by Treaster and Yocum (1979) and Pisasale and Ahmed (2002) are similar; the differences found in the values can be primarily attributed to the geometric construction characteristics of the probe.

## 4.1. Using the Method of Treaster and Yocum

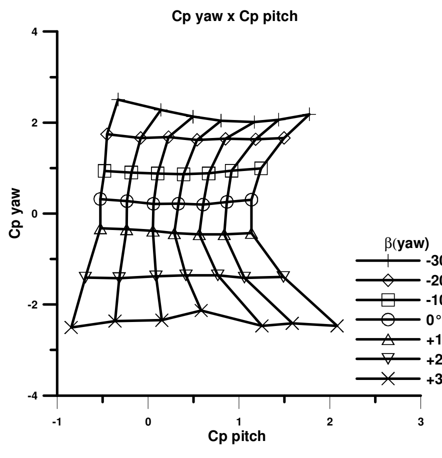


Figure 6a. Cp Yaw x Cp Pitch

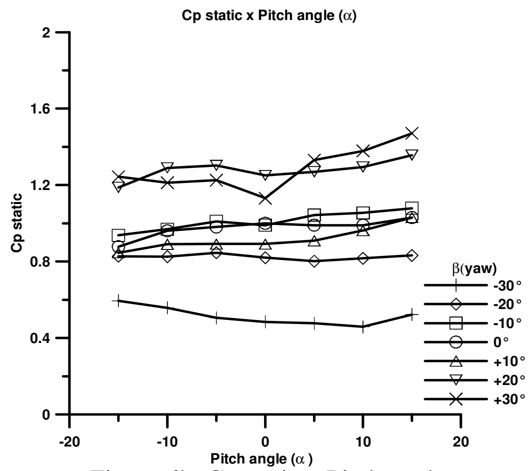


Figure 6b. Cp static x Pitch angle

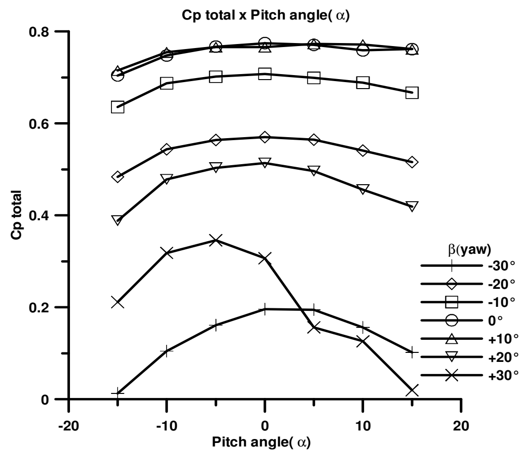


Figure 6c. Cp total x Pitch angle

### 4.2. Using the Method of Pisasale and Ahmed

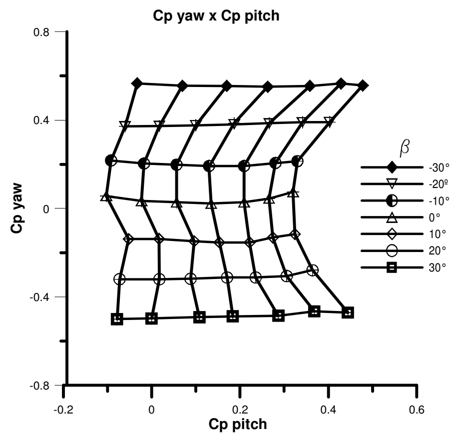


Figure 7a. Cp Yaw x Cp Pitch

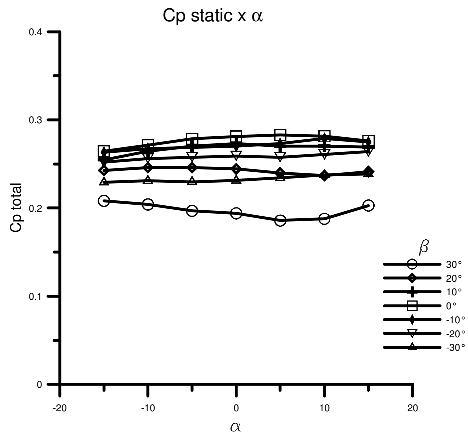


Figure 7b. Cp static x Pitch angle

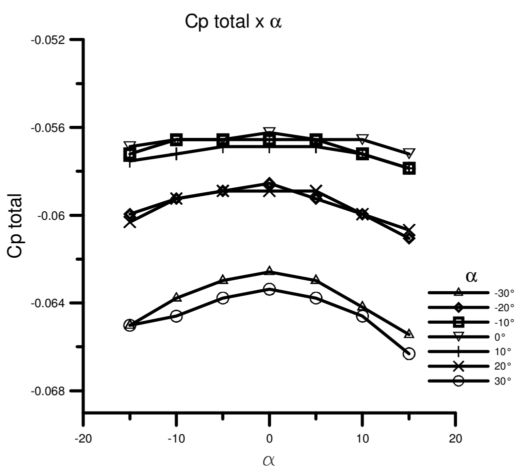


Figure 7c. Cp total x Pitch angle

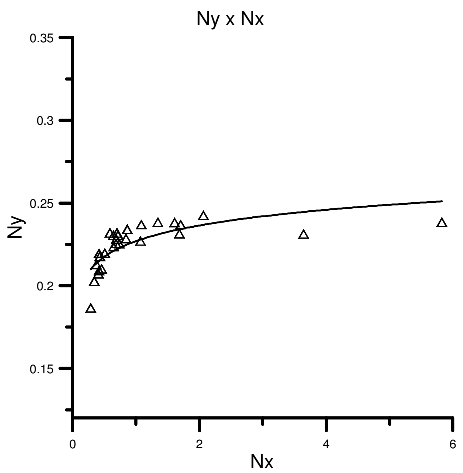


Figure 7d. Ny x Nx

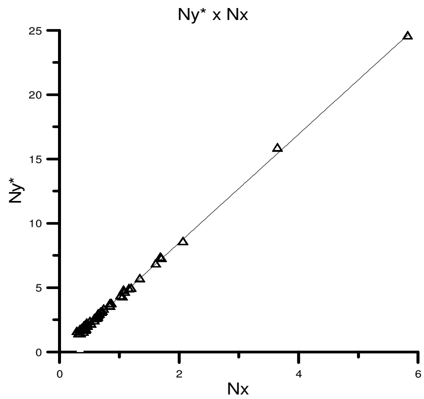

Figure 7d. Ny* x Nx

After the development of the two methodologies and obtaining its image, we can say that both approaches had good results, is showing very similar to literature. However, we could not make a good comparison of results from the methodology proposed by Pisasale and Ahmed (2002) with their literature, due to the fact that this work was used a fairly small range of angles. From the graph of pressure generated by the two approaches, it becomes possible to determine the velocity field in each section of the wind tunnel. These graphs will be used to obtain the values of the new non dimensional coefficients that will be introduced in the equations of Bernoulli (equations 6 and 15) to find the value of the magnitude of the mean velocity vector in each point of measurement.

From the calibration graphics generated by the two methods listed above, we can see that despite these methodologies follow relatively different paths, but their outcomes to follow the same direction. In light of this and coupled to the fact that the method proposed by Pisasale is a solution to the problem of the similarity occurrence when using large angles of calibration, which is not the case this work, was opted the adoption of the method of treaster for obtaining the field of speed in 7 sections of the wind tunnel.

The measures had been acquired following the project of the mesh represented in Figure 8, where each point used pressure probe in one given position to it, it fixes, with the direction and equal angles of deviation 0°.

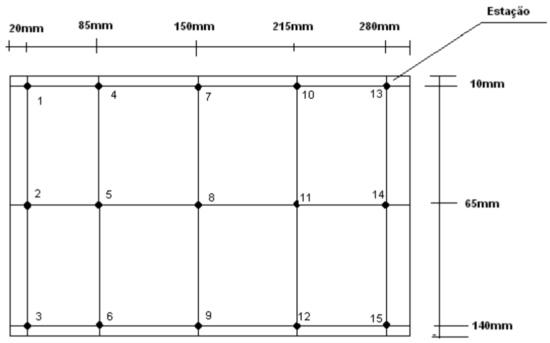


Figure 8. Schematic grid to establish the measure point on each plane.

Already in possession of data of pressure, were calculated the news Cp pitch and yaw for each station of measurement. These were inserted into the graphic of Cp yaw versus Cp pitch in order to find, through interpolations double linear (griddata function) of the commercial code MATLAB, the values of α and β. The values of α and β were reintroduced in the graphics Cp static versus α and in graphic Cp total versus α order to find, again using the MATLAB and the same function, the new values of Cp static and Cp total. Then it was possible to calculate the values of magnitude speed for each station of measurement using equation (6).

Analyzing the velocity graphs below, we can notice that: in the 1st section, the gradients of mean velocity show us a flow in development with the presence of a boundary layer like that seen on flat plate. In the 2nd and 3rd sections, the gradients of velocity show us, a significant reduction of longitudinal velocity near the outer wall of the curvature. Consequently, the longitudinal velocity of the flow begins to grow opposite of adverse gradient, as a result of conservation of the momentum.

In the 4th section, which is in the middle of the curve, we see the emergence of a region of low longitudinal velocity along the inner wall. This region is due to the possible existence of a zone of recirculation. With this, the area of greater velocity is moved toward the center of the section. In the external wall not had major changes and speed in the region is still low.

In the 5th section, the area is low-speed stretch horizontally to the center section due to increased recycling in this region. Influenced by this phenomenon, the areas of highest speed are moved to the top right and bottom right of the section. The velocities close to the external wall remain low.

In the 6th and 7th sections, located after the curvature, the effects of curvature still influence on profiles of velocity. Nearby the external wall and the center of the section there is an appreciable increase in longitudinal velocity, which observed the emergence of a zone of greater velocity in the outer wall of the longitudinal curvature, due to the inertia of the flow, causing the lines of current tend to leave tangent to the path of curvature. Due to problems of space, the graphics of 1 and 7 sections could not be displayed.

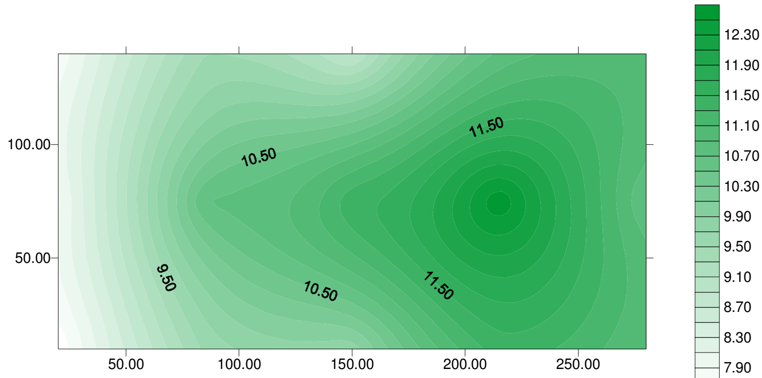


Figure 9(a) – Mean velocity field in section 2

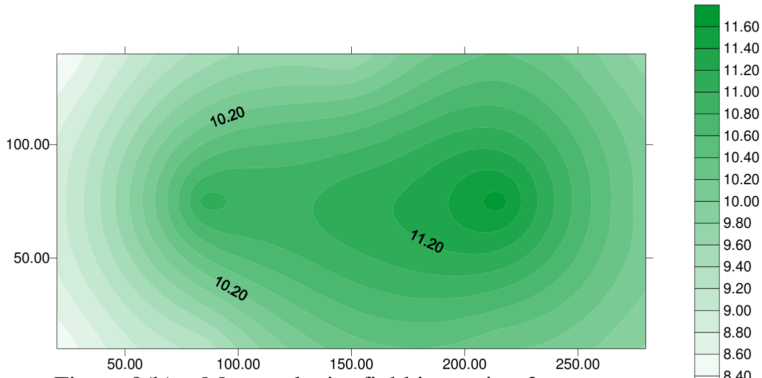


Figure 9(b) – Mean velocity field in section 3

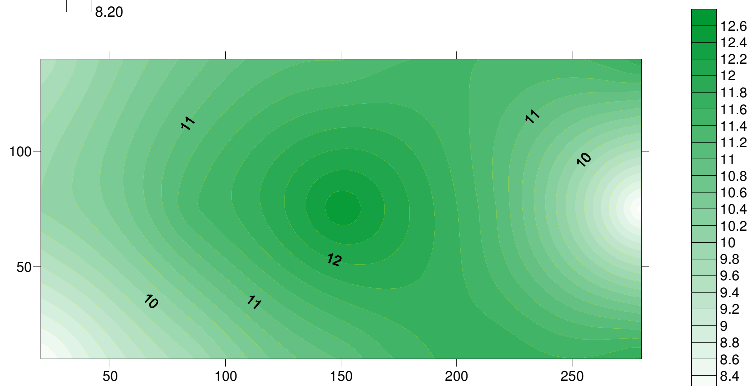


Figure 9(c) – Mean velocity field in section 4

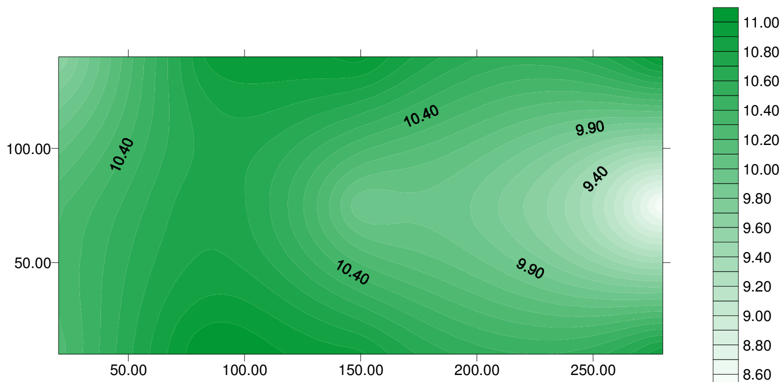


Figure 9(d) – Mean velocity field in section 5

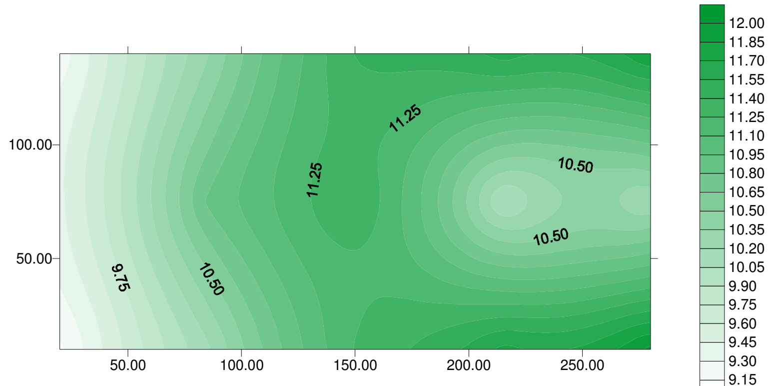


Figure 9(e) – Mean velocity field in section 6

## 5. CONCLUSION

In the present work it was used a five-hole pressure probe in the wind tunnel of the Laboratory of Fluid Mechanics of the UFPa. The results of the calibrations showed that the graphics of Cp Pitch versus Cp Yaw did not present the problem of singularity for angles lower than ± 30° in both used methods. Furthermore, these results are quite consistent with the literature studied. After analyzing the data of mean velocity generated in this work, we can say that the five-hole probe is a good alternative in prediction of outlets and three-dimensional phenomena of curvature.

The calibration and the measurements carried out through the pressure probe is an exhaustive procedure, although this type of probe is a good choice to provide information about the behavior of the flow in curved channel or complex flows like those found in turbo machines. Its use demand few financial resources when compared with other methods such as PIV and LDA (Laser Doppler Anemometry) and its simplicity in operation and methodology of processing the data collected. This preliminary study will support a future experimental work in a cyclonic flow.

## 4. ACKNOWLEDGEMENTS

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