PRESSURE PROFILE OF A CURVED CHANNEL BY A MULTIHOLE PRESSURE PROBE

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Abstract*. Flows with three dimensional effects are found in turbo machines and around complex bodies. These effects can be produced by channel with curved walls that provides curvature or changes in the streamline direction. The experimental study of the three-dimensionality and the structure of the turbulent flows, usually require optical techniques like the laser-Doppler anemometry or the particle image velocimetry systems, PIV. However, high costs of the experimental apparatus associated with these methods make these techniques inaccessible to man laboratories; this fact makes the measure technique using pressure probe a good option since it provides the pressure field. This paper reports the calibration and measurement procedures implemented to work with a five-hole pressure probe in the mapping pressure and velocity field in a wind tunnel flows. To obtain flow characteristics in terms of static and total pressure and three-dimensional components, the conventional method proposed by Treaster & Yocum (1979) which avoids the traditional non-nulling mode was used. The data are obtained from the pressure information given by five steel hypodermic tubes. These tubes have a 0.9 mm outer diameter and 0.5 mm inner diameter. The calibration was carried out in a wind tunnel test facility at all combinations of pitch and yaw angles from -30º to 30º.*

Keywords *: Five-hole , pressure probe , pressure field.*

1. INTRODUCTION

The experimental data in many fields of complex flows generally are obtained by using multihole pressure probes. These types of probe have been used in some forms to measure the components of velocity and the local field of pressure in three-dimensional flows as to those finding in rotating turbomachines or in flows around complex bodies. The application of these probes requires a careful calibration with the attainment of three-dimensional data. The pressure probe can operate in two forms: in the nulling or the non-nulling mode.

Lee and Ash (1956) had considered a method of calibration and measurements for a spherical pressure probe of five holes, the calibration method consisted of the probe adjustment until the axis point in the direction of the flow or the shunting line of the pressure probe, until the meridian plan passed through the center of the orifice that contain the angle of the flow. This proposal of calibration was considered an innovation since at the time there wasn't many proposals, however, this method is difficult to accomplish. This method can provide static pressure, magnitude and direction of the velocity vector measures.

Some calibration techniques of five holes pressure probe can be found in literature. One of them is a more common method than it was considered by Treaster and Yocum (1979). In the proposal technique the pressure probe is calibrated in the non-nulling mode or a fixed position. The technique is simple; however, singularities can appear when it is applied for high angles of direction or deviation. In the study of Treaster and Yocum (1979), a sensor prism with a diameter of 3.18 mm and a conical sensor with 3.81 mm of diameter have been used in a flow with Reynolds number in the range of 2000 to 7000, based on the sensor's tip diameter.

In the study of Dominy and Hodson (1993), the calibration was done in a different Reynolds number, in a range found in turbomachines flows. The authors had used the calibration mode and coefficients considered by Treaster and Yocum (1979) proposal. The result of the study confirmed the existence of the effect of two distinct Reynolds numbers, the compressibility showed to have small influence; however the turbulence can affect the trustability of the pressure probe calibration.

Nowack (1970) has constructed a special experimental apparatus which consisted on three perpendicular axis and a Cartesian calibration. In this type of calibration the direction of the velocity vector is determined by two Cartesian angles, the angle of deviation in the horizontal meridian plan and the angle of direction in the vertical plan; the method was considered for the calibration of a spherical Pitot tube with five holes. Morrison et al. (1998), they had considered a more sophisticated calibration technique which helps to reduce the calibration effect with points of bad quality and that does not require a symmetrical pressure probe perfectly. The technique consists in getting three-dimensional curves of the data set calibration which will make the compensation if it had been used a not symmetrical pressure probe, and also will soothe the effect of a bad quality points. The data has been obtained making the calibration in the non-nulling mode, the refinement was used and analytical expressions had been provided for the calibration functions.

In the study of Sitaram and Treaster (1995) the calibration technique application was the same one presented by Treaster and Yocum with modifications to use pressure probes with four holes. In this work the authors have used the pressure probe to measure the turbulent boundary layer on a flat plate. The authors had concluded that the results near the wall were not in accordance with the foreseen one by the theory.

Sitaran et al. (1981) has reported the measures of the relative flow that passes through rotor blades of an axial and induced flow using a conventional pressure probe as: the pressure probe of five holes and the spherical Pitot. The authors had been used the methods of calibration and interpolation proposed by Treaster and Yocum (1979). Ligrani et al. (1989) has described a miniature of the pressure probe of five holes which has a tip of 1.22mm in diameter. The pressure probe was developed to measure the three velocity components to be used in the procedure of non-nulling mode, at individual positions in a curved channel where the pressure differences are low. The flow was laminar and three-dimensional.

Wu J. Kim and Virendra C. Patel (1994) had been developed a study using a pressure probe with five holes to find the mean velocity and Reynolds stress components. In this work the authors had developed studies of the vortices which are formed near the curves in convex wall of the tunnel used in question. The turbulence was also measured in four test sections of the channel. The study had been done to elucidate the occurrences in the wind tunnel boundary layer however it shows the usefulness of the pressure probe.

B.J. Wendt and Reichert (1995) had grouped 10 pressure probes of five holes in an only pressure probe and they used them simultaneously to carry measurements of the three velocity components, total pressure and static pressure. In this work all the pressure probes had been calibrated, that's the importance of the calibration come from, recurrent subject in this work. D.G. Gregory Smith and J.G.E. Cleak (1992) have developed a study on a turbine rotor in cascade format to have a better understanding of the turbulent structure of the flow, including the contribution of the Reynolds stress. For this work, the pressure probe with five holes had been used.

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.

The objective of the present work is to apply the calibration method proposed by Treaster and Yocum which avoids the traditional non-nulling mode. The static and total pressure were obtained through a pressure probe with five holes. The data set are shown in terms of the total pressure to characterize the pressure field of the wind tunnel. The calibration was carried out in a wind tunnel test facility with all combinations of pitch and yaw angles from -30º to 30º

2. EXPERIMENTAL APPARATUS

A photo of the experimental apparatus is shown on Figures 1 and 2. The wind tunnel used to accomplish the calibration probe and obtain the data set is located in the Laboratory of Fluid Mechanics of the Department of Engineering Mechanics at Federal University of Pará.

The wind tunnel 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. 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 the a Pitot tube inserted in the flow.

The pressure probe that was used in the present study is shown in Fig. 3. 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.

Figure 2. The curved section.

These tubes have been inserted in an aluminum tube of 4.0mm external diameter and 40,0mm length. The hypodermics tubes are connected to the hair copper tubes and then they are connected to a manometer through flexible tubes for the pressure measurement. The tips of the pressure probe have been manufactured with an angle of 45º in relation to the tip of the central tube. Details of the construction can be found in Gouveia et al. (1997).

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 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. 4.

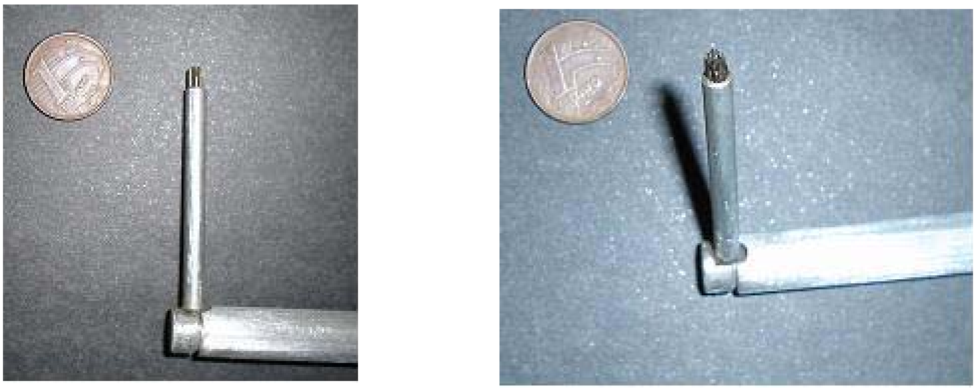

Figure 3. The five-holes pressure probe.

Figure 4. Mechanism used to allow the angle variation.

3. CALIBRATION PROCEDURE

The pressure probe used in this work was a pressure probe with five holes; 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 α and τ are the angles that define the velocity vector. These angles are defined as the angle in the yaw plane α, and in the pitch plane, τ.

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 in the interior of the wind tunnel. The exits of the tubes are connected independent one of the other through flexible tubes in a manometer.

The establishment of a completely developed flow in the entrance of the test section was necessary before begin the calibration. The flow was defined with a velocity of 10 m/s through the measure of the velocity profile in a section located before the section test where the pressure probe was located using a Pitot tube.

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 15º in the pitch plane, and -40º +40º in the yaw plane. For each variation five readings of pressure are obtained. Figure 5 presents a schematic drawing of the angle variation and the tip of the pressure probe.

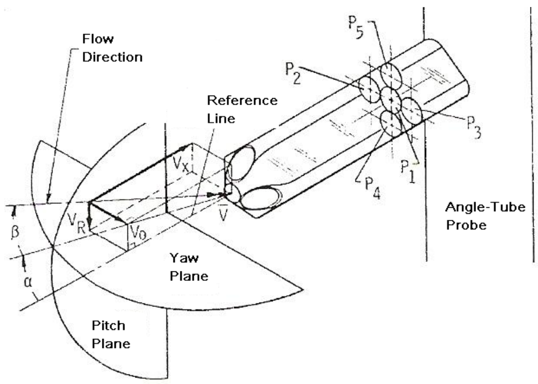

Figure 5. The pressure probe's tip, Treaster (1979).

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 $\overline{P}$ is considered the static pressure. Consequently the difference between P1 and $\overline{P}$ pressures represent the dynamic pressure which are used to obtain the calibration coefficients of pressure.

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

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

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

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

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

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

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 -30 up to +30, and the yaw angle of -15 direction up to +15. The calibration procedure was repeated three times to verify the repeatability of the results.

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 6 presents the localizations of each plan.

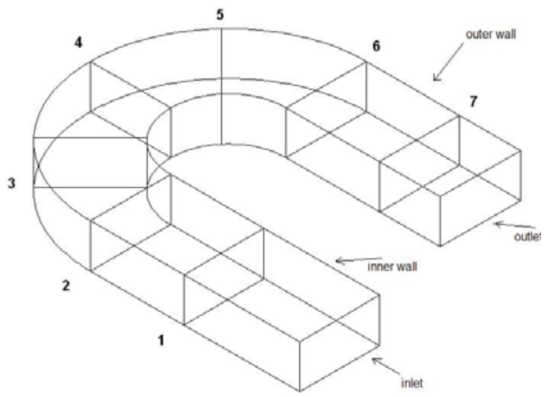

Figure 6 – Schematic draw of the seven planes on the curved channel.

The results of the calibration had been placed in terms of the nondimensional coefficients of pressure considered by Treaster and Yocum, which are functions of the flow angularity. The traditional plot of the calibration data is presented in Fig. 7a-c. The Fig. 7a is analyzed to examine the existence of some singularity; it was observed that for angles higher than ±30° there is singularity. This fact determined the angle range of this study between ±30°. Figures 7b and 7c show the variation of Cp static and Cp total with α for constant values of β.

The calibration data for the probe used in this study and that one used by Treaster and Yocum are similar; the differences found in the values can be primarily attributed to the geometric construction characteristics. The probe in study presents a smaller range of Cp pitch and Cp yaw. Cp static and Cp total versus pitch angle presented different ranges, both of them are smaller than that presented by Treaster and Yocum, however, they present a similar behavior.

In this work the behavior of the total pressure is also presented, the measure with the pressure probe of five holes; these measures had been got in various sections of the curve connected to the wind tunnel. A mesh in each plan was elaborated to get the measures of pressure, had been gotten 75 measures in each section being that they had been 5 sections, then to all will have 375 data of pressure throughout the curve.

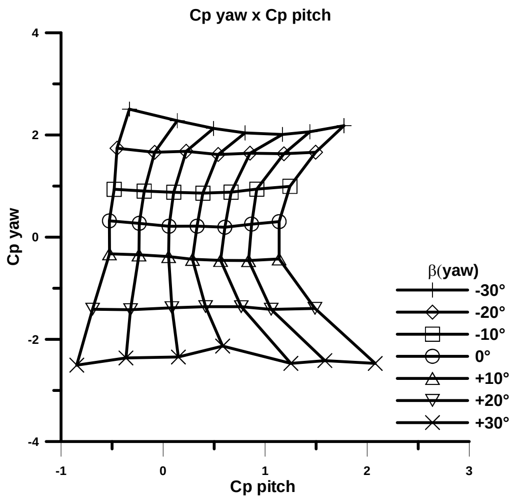

Figure 7a. Cp Yaw x Cp Pitch

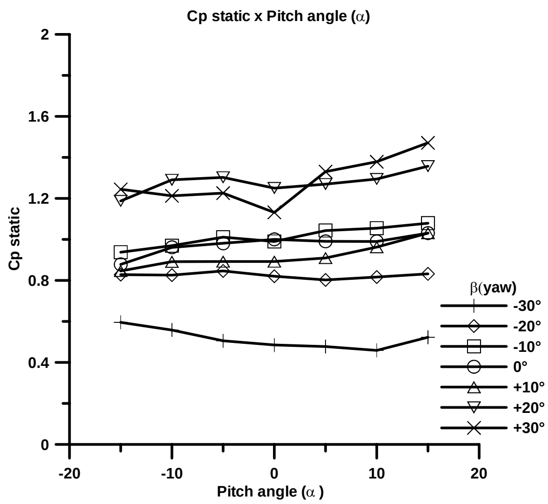

Figure 7b. Cp static x Pitch angle

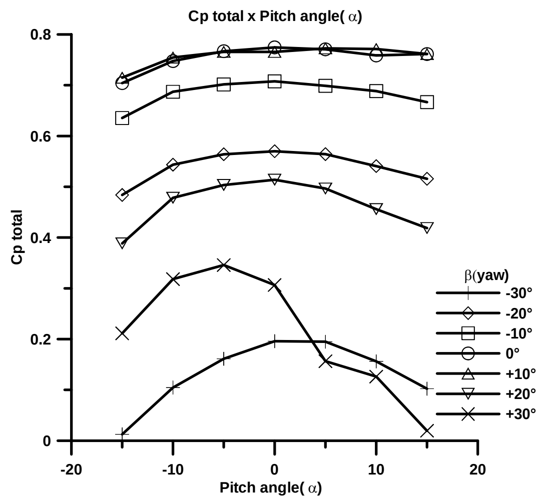

Figure 7c. Cp total x Pitch angle

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°

In each predetermined point of the flow five readings of pressure have been obtained, therefore each reading refers to an existing hole in the pressure probe. The existing numbers in the mesh represented in Fig. 8 are the data acquisition order. After the measurement procedure, the data set was reduced to obtain the pressure values.

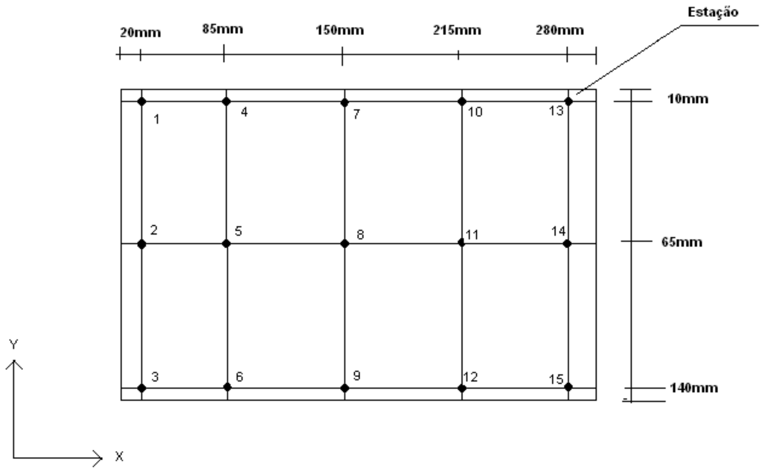

Figure 8. Schematic grid to establish the measure point on each plane.

The total pressures of each numbered point had measured from the central hole of the pressure probe; the result is presented in the graphical form in lines of contour for each one of the sections or plans, and it is presented on the Fig. 9a-g.

Analyzing the pressure graphs below, we can notice that: in section 1 the total pressure is higher at the centre of the section; in section 2 it is observed that the pressure is well distributed and is the section where the flow is in completely development. The section 3 is located at the first strong curvature, in this is possible to note that the pressure decreases on the inner wall, by the principles of fluid mechanics, where the pressure is minimum the velocity is maximum, it means that exist an increase of the mean velocity.

The behavior of section 4 confirmed the behavior observed in the previous section 3. There is a maximum pressure value on the outer wall and a minimum on the other side; these values vary from 101,940Pa to 101,880. The section 5 is the second strong curvature; in this it was observed that the pressure has a little decrease on the outer wall and a little increase on the inner wall. This behavior is observed gradually until the section 7.

On plane 2, the velocity profile shows a flat plate type boundary layer. Plane 3 is the position where the curved section begins, on this plane the longitudinal velocity increase near the inner wall.

On plane 3 the longitudinal velocity increases closer to the inner wall and decrease until the outer wall. These effects are repeated in the middle of the curvature on plane 4. On plane 5, the effect is changed, the longitudinal velocity is increased near the outer wall and presents diminish close to the inner wall. It was observed that the pressure distribution along the channel walls is strong determined by the curvature. The pressure gradients induced by the curvature are clearly seen. The results indicated that on the inner wall, the boundary layer is subjected to a favorable pressure gradient starting upstream of the bend, close to the plane 2.

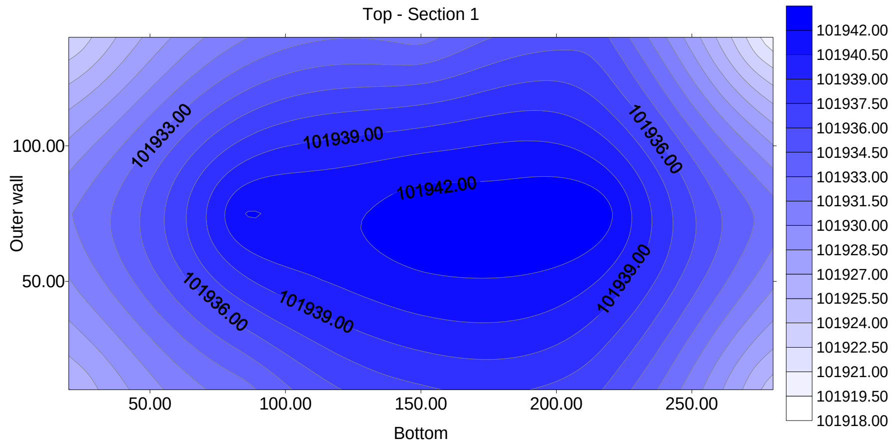

Figure 9(a) - Pressure field in section 1

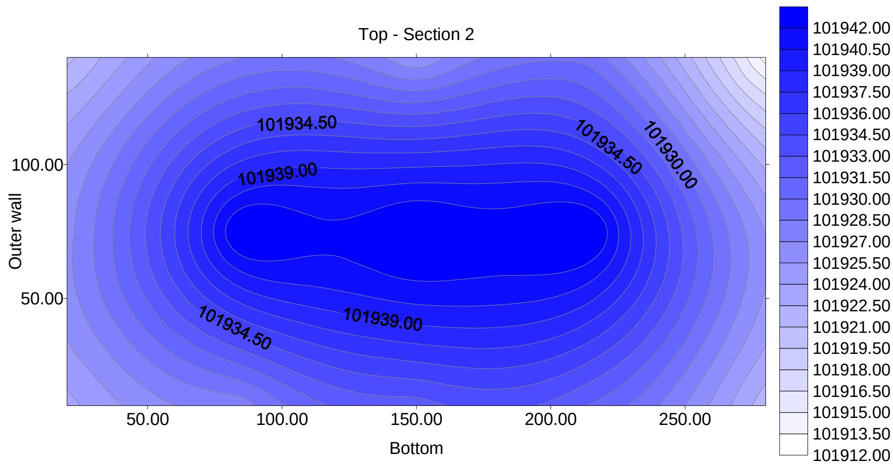

Figure 9(b) - Pressure field in section 2

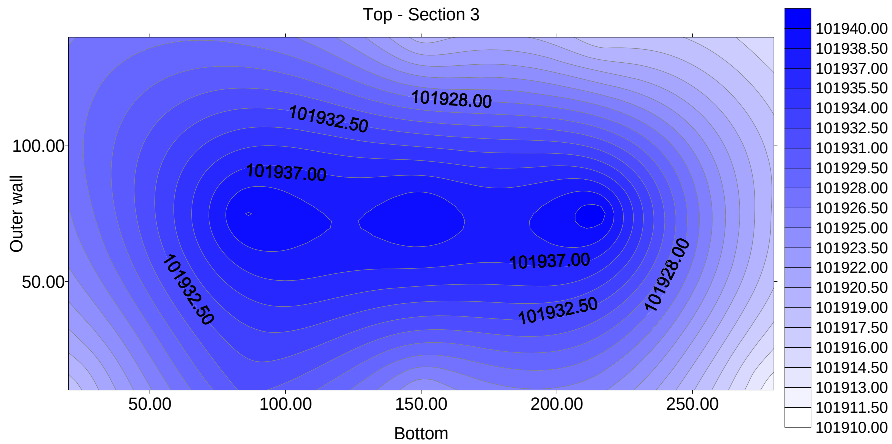

Figure 9(c) - Pressure field in section 3

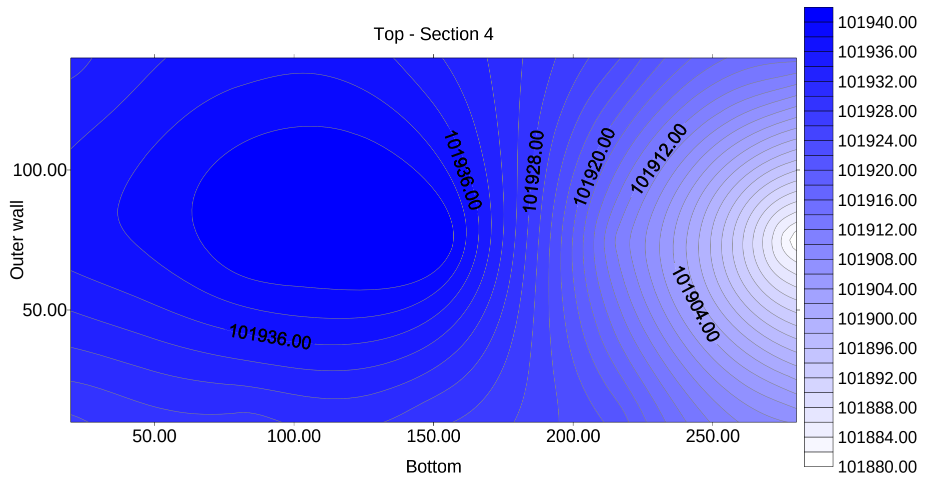

Figure 9(d) - Pressure field in section 4

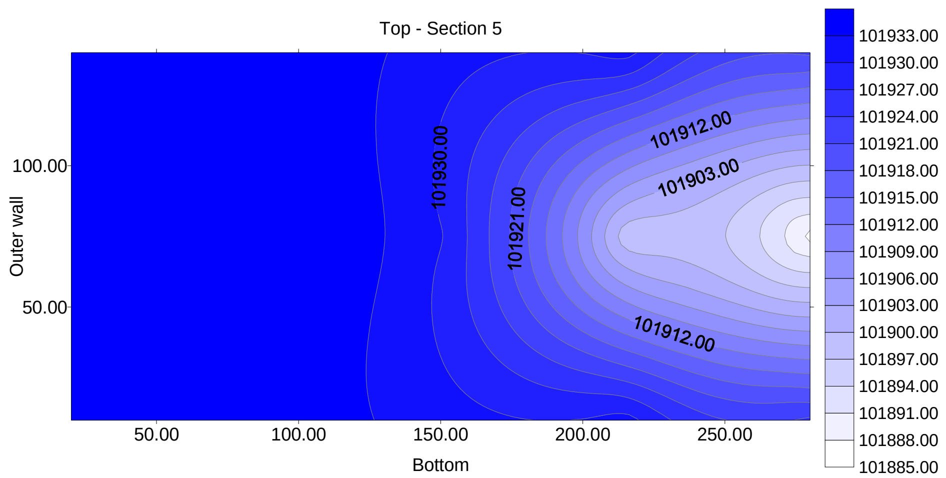

Figure 9(e) - Pressure field in section 5

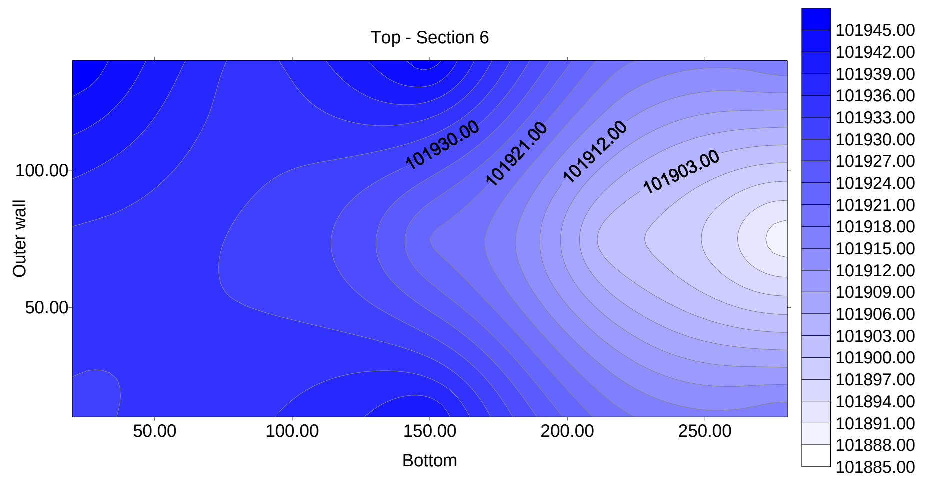

Figure 9(f) - Pressure field in section 6

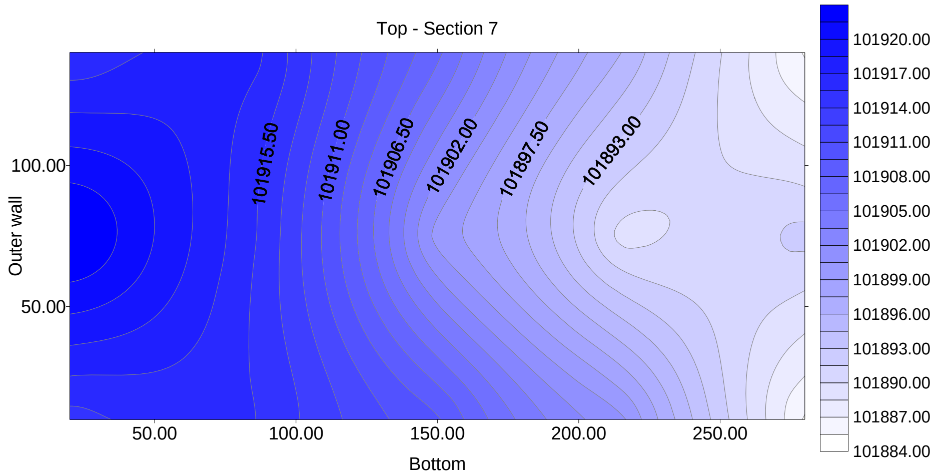

Figure 9(g) - Pressure field in section 7

5. CONCLUSION

In the present work it was used a pressure probe of five holes in the wind tunnel of the Laboratory of Fluid Mechanics of the UFPa. The analyzed calibration method proposed by Treaster and Yocum provided good results. The total pressure was obtained from the pressure information from five steel hypodermic tubes. The result of Cp Pitch versus Cp Yaw did not show the problem of singularity for angles lower than ± 30°. 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 turbomachines.

In this work it was possible to measure the pressure field along the curved channel; the obtained data set showed coherent results to the theory. This work is a preliminary study and the first step to measure and obtain the three velocity components in a complex flow using the pressure probe with five holes.

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