FIVE-HOLE PRESSURE PROBE CALIBRATION FOR APPLICATION INTO CYCLONIC CHAMBER

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Abstract.*Complex flows of fluids are usually found in nature and have multiple applications in engineering. The experimental study about it is of great scientific and technological area, especially in aeronautic, meteorological and oil-gas fields. The measurement of this kind of flow obtained greats advances using optical techniques as Laser Doppler Anemometry (LDA) and Particle Image Velocimetry (PIV). However, the instruments for these techniques are quite expensive becoming inaccessible to many laboratories. Therefore, the multihole pressure probe becomes a feasible alternative to detail the complex flow behavior, once it has a low cost of manufacture and supplies the pressure and average velocity fields, taking advantage between other measurements techniques previously reported that do not have this resource. In this work it is described the procedure for calibrating a hemispherical water-cooled five-hole probe for application in combustion chamber, using the reference system with relation to α (yaw angle) and β (pitch angle) for determining the velocity field. Such a system is expressed in terms of the horizontal angle α and the vertical angle β, which are projection angles of the velocity vector on the horizontal plane and on the vertical plane with relation to the axis of the probe.*

Keywords*: probe, five hole, complex flow, calibration, flow characteristics*

1. NOMECLATURE

P_n	Pressure at port *i*	$\bar{P}$	Average pressure
$C_{P_{yaw}}$	Yaw Coefficient	P_{static}	Static pressure
$C_{P_{pitch}}$	Pitch coefficient	P_{total}	Total local pressure
$C_{P_{total}}$	Total presure coefficient	P_{ref}	A reference pressure
$C_{P_{static}}$	Static pressure coefficient	**Greek symbols**	
		α; β	Yaw angle; pitch angle

2. INTRODUCTION

Complex flows are usually in great abundance in various technological processes as oil extraction, refining and pipeline transporting; calcination in the mining industry, air pollution and aeronautic and meteorological fields. This variety of applications shows the importance of studying in this area of Fluid Mechanical. Three dimensional characteristics of this kind of flow are required, for this aim there are other measurements techniques as Laser Doppler Anemometry (LDA) and Particle Image Velocimetry (PIV), but these techniques are quite expensive becoming inaccessible to many laboratories. Then, multiholes pressure probe becomes more workable and there are an extensive range of studies about it. Despite that being an intrusive device, the results obtained with multi-hole probes are not so different from those obtained with the use of non-invasive methods, such as laser anemometry (Beltagui et al., 1993).

Five-hole probes are basically Pitot tubes capable of making five pressure measurements that properly connected to a manometer allow to obtainment both of the direction and the velocity magnitude of flow. The constructive design of this kind of probes can be found commercially in several configurations such as spherical, conical, prismatic and others. The hemispheric type is originated from the development spherical head proposed by Lee and Ash (1956) that describes its construction and calibration procedures for the determination of the flow in a turbomachine rotor.

Hemispheric five-hole probe with forced water cooling is usually used in combustion chambers. The five hole pressure probe used in this study has as objective its application on a combustion chamber. To understand the combustion dynamics inside of the combustion chamber, and through this analyze the phenomena involved in the combustion process, it is essential to know the velocity measurement and the direction of the flow of combustion gases inside the chamber. Such goal is ambitious since the flow is of high complexity (rotating, two-phase, reactive, with high temperature gradients, etc.). A literature review revealed the history and applications of the instrument, which is presented briefly in the following paragraphs.

Nowack (1970) proposed a calibration method for five-hole spherical probes by which the direction of a velocity vector is fixed by two cartesian angles in order to obtain the velocity fields of rotating machines. Regarding probes for specific use in combustion chambers, Chedaille and Braud (1972) describe probes that were used in researches carried out at IFRF - International Flame Research Foundation.

Some techniques for the calibration of five-hole probes can be found in the literature. The most common was proposed by Treaster and Yocum (1979). In this technique the probe calibration is known as being of the type non-nulling or fixed position. Its use is simple, but there may be singularities when it is used for large deviation or direction angles. In this study it was also shown the manufacturing and calibration of two probes, one of them being of the prismatic type and the other with the geometry of tubes with 45 degree angle. Both of them were applied to obtain the velocity fields in turbomachines.

Sitaran et al. (1981) reported the measurements of a flow passing through the blades of an axial-flow rotor using conventional probes as a five-hole probe and Pitot tube. The calibration and interpolation methods used were those proposed by Treaster and Yocum (1979). Ligrani et al. (1989) described a miniature five-hole probe which has a tip diameter of 1.22 mm. The probe was developed to measure the three velocity components using the non-nulling technique in individual positions of a curved channel where the differences in pressure are low, and the flow is laminar and three-dimensional.

In this work it is described the procedure for calibrating a hemispherical water-cooled five-hole probe (Fig. 1) for application in combustion chamber, using the reference system with relation to α (yaw angle) and β (pitch angle) for determining the velocity field. Such a system is expressed in terms of the horizontal angle α and the vertical angle β, which are projection angles of the velocity vector on the horizontal plane and on the vertical plane with relation to the axis of the probe, as shown in Fig. 2.

3. EXPERIMENTAL APPARATUS

The calibration of the five-hole probe (see Fig.1) was conducted in a open-circuit wind tunnel (see Fig. 2) which has along straight duct followed by an 180º curved section(0.3m x 0.15m).The air is supplied uniformly by a centrifugal fan which its rotation is controlled by a variable frequency device. For this work, the velocity flow was fixed in 10 m/s (859.8 rpm) which was previously established by a Pitot tube insert into the flow. This pressure probe is constituted by five steel tubes with external diameter of 0.5 mm and 700 mm of length. As they are five tubes it is necessary to get the pressure in each one of them. The data acquisition for the pressures was measured using a digital micromanometer (FCO510) from Furness Controls Ltd.

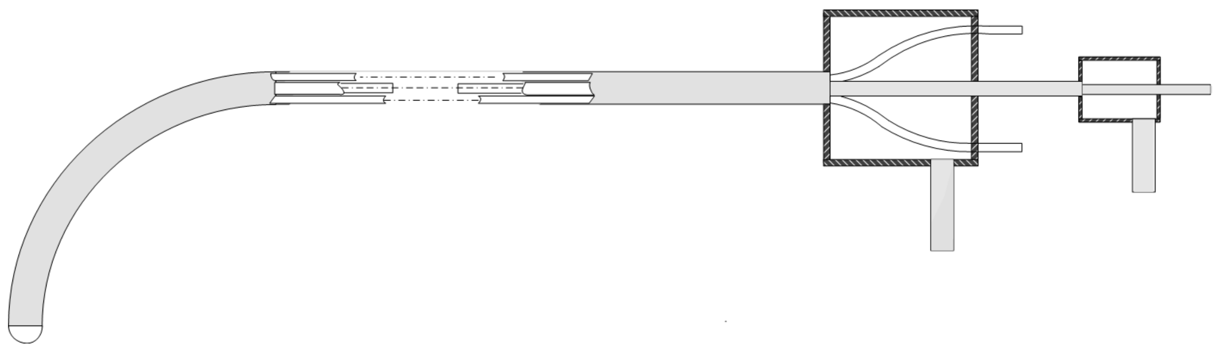


Figure 1. Geometry of the hemispheric five-hole probe.

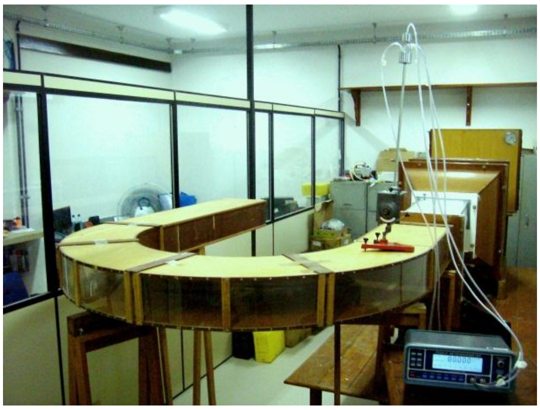
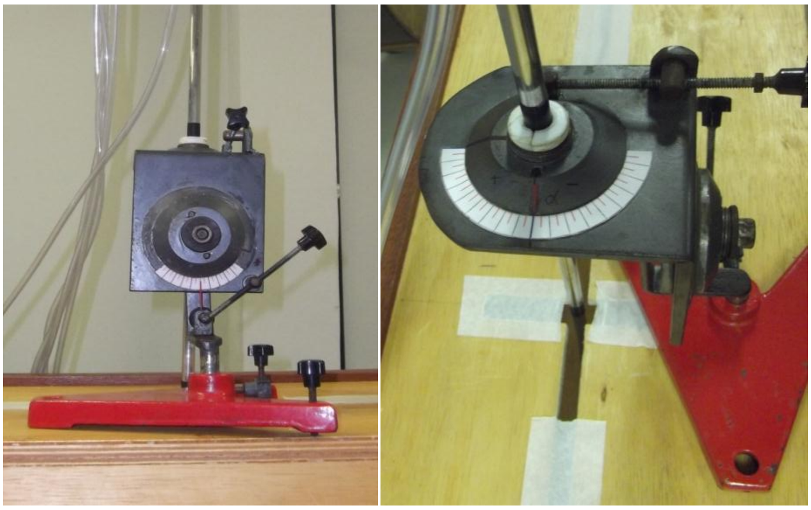


Figure 2. Open-circuit wind tunnel.



(a) (b)

Figure 3. The yaw-pitch calibration device: (a) Setting yaw angle and (b) Setting pitch angle

The rotation in the yaw and pitch planes was realized by a mechanism which consist a support that enables these movement relative to probe ports. This yaw-pitch calibration device is shown in Fig. 3. Where in (a) shows the pitching set and in (b) shows the yawing set. Positive roll is counterclockwise when looking atop at the device.

4. CALIBRATION PROCEDURE

4.1 Hemispheric Probe Calibration

This calibration procedure was based on Treaster e Yocun (1979) method which the five-hole probe might used in a fixed position or non-nulling mode. In this work the pressure probe was calibrated on a non-nulling mode in which the pressure difference are in function of the. In this work the probe was calibrated in a non-nulling mode in which measurements of pressure differences due to the angularity in planes flow direction and deviation, are expressed as dimensionless coefficients following Equations 2, 3, 4, 5 and 6.

The yaw-pitch calibration device, which was installed in the test section permitted a ±30º rotation in yaw and ±25º deg in pitch, both to an accuracy of 5º.

The reference static pressure was recorded by a wall-pressure tap in the test section and atmospheric pressure was used as the reference total pressure.

During the calibration, the velocity was maintained at a constant value which was set on a variable frequency device. Afterward, the probe is first aligned in the wind tunnel at zero yaw angle which is defined to be that angle when the pressure at port 2 and 3 are equal. Then, the probe is manually fixed at a known yaw angle and followed by rotation through the pitch plane. A total of 77 angle combinations are used: eleven pitch angles and seven different yaw angles. At each calibration points, five differential pressures ΔP_i (Eq.1) were measured, through flexible tubes, apart processed by a digital micromanometer which was connected a computer where data was recorded.

$$\Delta P_i = P_i - P_{ref} \tag{1}$$

4.2 Mathematical Equations

Figure 4 shows the schematic arrangement of the five holes ports. As said previously, the probe was placed in a known flow and varied the pitch and yaw angle in accord with the calibration procedure for the non-nulling method. There are four coefficients which are used to calibrate, as follows:

$$C_{P_{yaw}} = (P_2 - P_3)/(P_1 - \bar{P}) \tag{2}$$

$$C_{P_{pitch}} = (P_4 - P_5)/(P_1 - \bar{P}) \tag{3}$$

$$C_{P_{total}} = (P_1 - P_{total})/(P_1 - \bar{P}) \tag{4}$$

$$C_{P_{static}} = (\bar{P} - P_{static})/(P_1 - \bar{P}) \tag{5}$$

$$\bar{P} = (P_2 + P_3 + P_4 + P_5)/4 \tag{6}$$

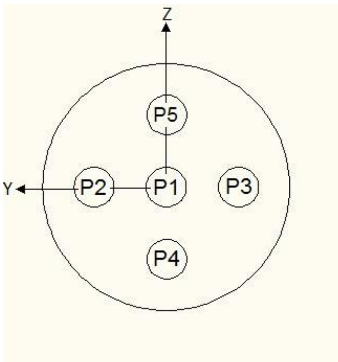


Figure 4. Port numbering.

5. RESULTS

The results of the calibration data for hemispheric five-hole probe which was based on Treaster e Yocun (1979) methods presented in Fig. 5, 6 and 7. Shown in Fig. 5 are grids of $C_{P_{yaw}}$vs $C_{P_{pitch}}$, where the horizontal spline curves are curves of constant α and the vertical spline curves are curves of constant β. Figures 6 and 7 show, respectively, the variation of $C_{P_{static}}$ and C_{total} with β for constant values of α.

As said in the calibration procedure, for each yaw angle (-20º to +20º) and pitch angle (-25º to +25º) in an only section were recorded five pressure measurements. This procedure was repeated three times to verify the repeatability of the results which was averaged.

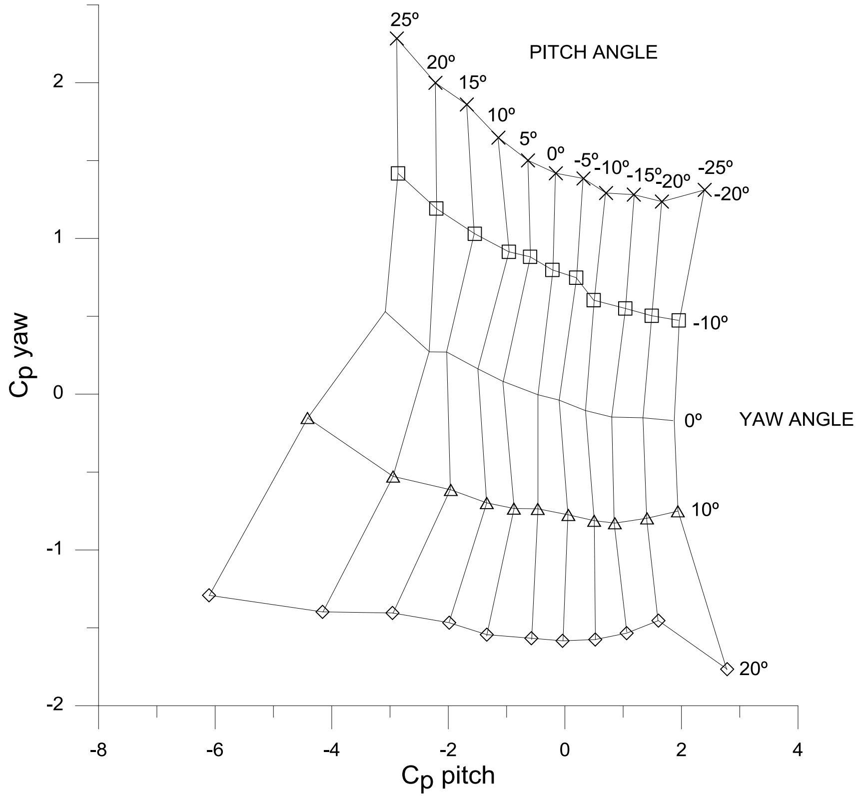


Figure 5. $C_{P_{yaw}}$vs $C_{P_{pitch}}$.

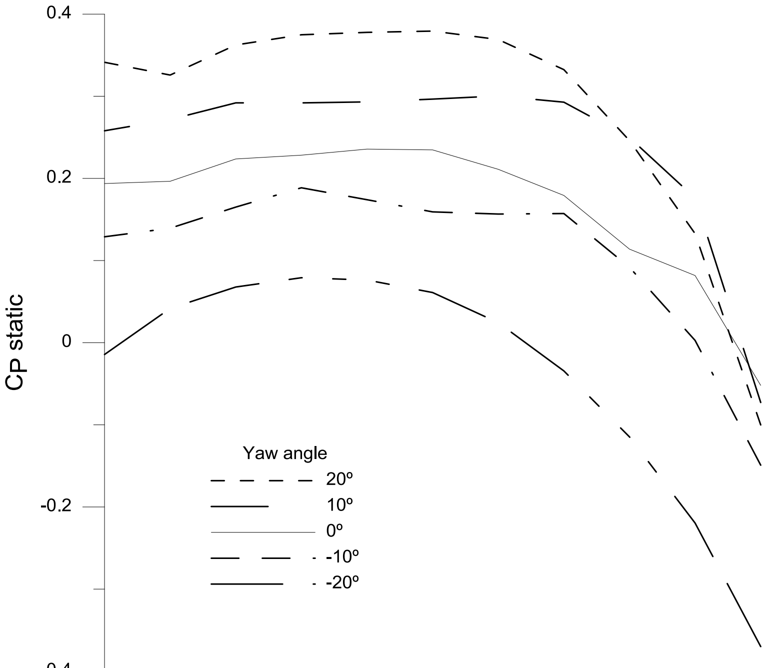


Figure 5. $C_{P_{static}}$vs pitch angle.

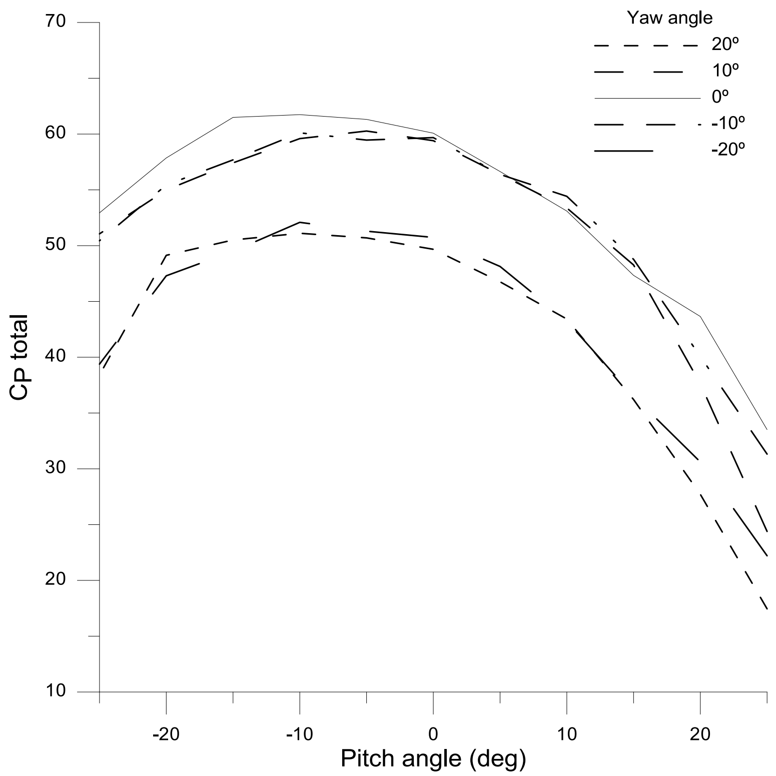


Figure 5. $C_{P_{total}}$vs pitch angle.

6. CONCLUSION

The method of Treaster and Yocun for calibration of a hemispherical five holes was presented. This method is simple and easy to perform. Therefore, it is confirmed that the calibration method may be used to probe hemispherical five holes. Was observed simplicity in the operation, greater attention was given to the positioning mechanism of the probe once the desired angle adjustment was done manually. In these tests the calibration method used had no difficulties in data analysis and provided dimensionless coefficients in agreement with literature. However, the literature is not clear on the fact that this is the most appropriate method for a probe of hemispheric type.

The pressure measurements and graphs of calibration constants showed good repeatability measurements in three rounds. The graphics are consistent with existing literature.

In a future study another calibration method will be used to compare and identify which method has a greater range of angles calibration without presenting singularities. After the calibration method is completed to the probe under consideration, it will be used in a combustion chamber with rotating flow.

8. ACKNOWLEDGEMENTS

We want to acknowledge CNPQ for make this work possible.
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