Design, Fabrication and Calibration of a Five Hole Pressure Probe for Measurement of Three Dimensional Flows

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Abstract

The accuracy in measurement of flow rate of liquids and gases is an essential requirement for maintaining the quality of industrial processes and the industrial control loops are used to control the rate of flow of incoming liquids or gases so as to achieve the control objective. Different types of flow measuring techniques are being used in various industries. The common types of flowmeters used in industrial applications are : (a) Obstruction type (differential pressure or variable area) (b) Inferential (turbine type), (c) Electromagnetic, (d) Positive displacement (integrating), (e) fluid dynamic (vortex shedding), (f) Anemometer, (g) ultrasonic and (h) Mass flowmeter (Coriolis). Pressure probe is one of the common instruments used to measure the stagnation pressure, the static pressure, and the flow angle within a fluid stream. When we are designing a pneumatic probe for flow measurements, the effects of blockage, frequency response, pressure hole size and geometry, the local Mach and Reynolds numbers and the relative scale of the phenomena under study must be addressed. Five-hole probes are a newer type after the development of two-hole Conrad and three-hole Cobra probes which are used to measure the pitch and yaw angles of the flow, the stagnation pressure and dynamic or static pressure. Here, five hole probe is fabricated and then calibrated by using continuous wind tunnel. It can be extensively used for three dimensional flow measurements. It is a good alternative to costly techniques of flow measurement.

Keywords- Multi-Hole Pressure Probe, Five-Hole Probe, Calibration, Cp PITCH, CpYAW, Three-Dimensional Flow, Araldite Cladex Solution, Stagnation Pressure, Micro Manometer

I. INTRODUCTION

Multi-hole pressure probes are used for measurement of three-dimensional flows due to their reliability, rigidity and ease of manufacture. Also they can provide local measurements of the three components of fluid velocity as well as of the local static and total pressure. The design, calibration and use of five-hole probes are developed here in this work. Calibration process is characterized by the identification of non-dimensional pressure coefficients which are as sensitive as possible to the flow angles. These coefficients are then measured in steady flow over a range of incident flow angles during a calibration procedure; the range of angular sensitivity will depend on both the velocity magnitude and the probe tip geometry.

The static and total pressure is also identified. Calibration process delivers four calibration functions relating the non dimensionalised pitch angle, yaw angle, static pressure and total pressure to the pressures measured at the probe ends. At any experimental measurement, the four coefficients are computed from the pressure readings, and the corresponding pitch angle, yaw angle, static pressure and total pressure are obtained by interpolation or by use of functions. The velocity magnitude may be determined from the static and total pressures. The velocity components in X, Y,Z (Cartesian coordinates)may then be resolved.

This work focusses on the use of a generalized calibration scheme with probes having five holes, and analyse the robustness of the data reduction algorithm against those discussed at the top. Pressures at all five holes are measured for each angular position of the probe. The data's obtained are characterized as non-dimensional pressure coefficients. In fact, pressure probes are mainly used in turbo machinery applications.

Generally, calibration is carried out in open jet wind tunnel. It is maintained at a constant velocity of 25 m/s, which was measured using a pitot-static tube kept in the flow. The total and static pressure of the free stream were also measured, and the five-hole probe was set up in the flow, with arrangements to change its pitch and yaw angles relative to the air flow direction.

II. LITERATURE SURVEY

S.J. Lien, et al [1], author studied the problems of misalignment to flow direction and the necessity to drill a tap hole on the surface to obtain total and static pressures by utilising a Preston probe in skin friction measurement in a turbulent flow a tedious task. The investigation was done on the use of a multi-hole pressure probe in a non-nulling mode to overcome these problems The near-wall effect on multi-hole pressure probe readings was examined both experimentally and theoretically. The results indicate that the wall effect was negligible. Experiments were repeated out in a pipe, on a flat plate to simulate one, two, and three-dimensional turbulent flows. The skin friction coefficient determined using the multi-hole probe was found to have similar results with published data.

M. Yasar, et al [2], author investigated a multi-tube pressure probe calibration method in swirling flows. Calculation of flow direction associated with, α, and yaw, Ψ, angles, magnitudes of local static and dynamic pressures can be obtained by the use of a calibration method for 3 tube probe and 5 tube probe chapters of a multi-tube pressure probe. The 5- tube probe was tested in a conventional air cyclone in which a strong rotational flow prevailed while the 3-tube probe was used in a low swirl flow field in a pipe which is internally fitted with a helical coiled wire insert. This method was based on the rotational sensitivity of the pressure probe handled through non-dimensional calibration parameters. He concluded that in comparison with LDV and Hot-wire probe measurements, the presented method is simple and cheap with not much difference in measured quantities.

L.J. Fingersh, et al [3], involved wind tunnel calibration of 5-Hole Pressure Probes for Application to Wind Turbines. Quantification of the local inflow vector on a rotating turbine blade using a 5-hole static pressure probe was developed at the National Wind Technology Center. This process permits quantification of dynamic pressure, angle-of-attack and cross-flow-angle magnitudes of ± 40° in any inflow direction parallel to the probe axis.

R. Paul, et al [4], demonstrated a novel calibration algorithm for five-hole pressure probe. Here the steady-state measurements of three velocity components, inflow angles, static and total pressures simultaneously for a point in a flow field. Numerous calibration algorithms for five-hole probes are referred in this paper as reported in the literature. Authors defined non-dimensional pressure coefficients in various ways. Here in this work, a new set of pressure coefficients were, which overcome the limitations and gave less computational errors in calculating the flow parameters. In this technique, the effect of pressure recorded by central hole is considered in describing these coefficients. 4th order regression analysis, the average values of r2 parameters were obtained for all zones as 0.9979 and 0.9910 for α and β respectively, and which are even better than that in the all existing methods.

Demetri Telionis.et.al, [5] Accurate calibration provides information which can then return three components of the fluid velocity as well as static and dynamic pressure. With the development of modern methods like LDV, particle-image velocimetry, the use of these probes has reduced. But the evolution of low pressure sensors, new multi-hole probes were designed and tested to match some of the features of other methods. Further, multi-hole probes are rigid and robust. It can sustain adverse condition, like very high temperatures, flows carrying particulates and similar others. Moreover, they are easier to use and less expensive. In the present paper they reviewed recent developments in multi-hole probe technology, mainly, fabrication and calibration methods that increases the frequency response of the probe , allow them to take data in wide ranges of the Mach number, and correct for inertial effects. We also present examples of using these probes in many industrial settings.

A. J. Main, et al [6], calibrated a four-hole pyramid type probe and area traverse measurements in a short-time transonic turbine cascade tunnel. The probe is used to create area traverse maps of total and static pressure, and pitch and yaw angles of the flow downstream of a transonic annular cascade. This data was acquired in a short duration (5 s of run time) annular cascade blow down tunnel. The probe used had a 2.5 mm section head, and has its side faces inclined at 60°to the flow to improve transonic performance. The calibration was done in an ejector driven, transonic tunnel with perforated wall over the Mach number range 0.5-1.2, with pitch angles from - 20° to + 20° and yaw angles from -23° to + 23° . A novel method for converting the probe calibration matrix of the raw coefficients into a probe application matrix of the physical flow variables (pitch, yaw, Mach number etc) was developed. The probe application matrix is then incorporated as a fast look-up table to process probe results. With very minor loss of accuracy, this method is faster by two orders of magnitude than the alternative of global interpolation on the raw probe calibration matrix. The blow down tunnel (mean nozzle guide vane blade ring diameter 1.1 m) creates engine representative Reynolds numbers, transonic Mach numbers and high levels of inlet turbulence intensity. Contours of measurements from the experiment at three different engine conditions and two axial positions have been obtained. An analysis of the data was presented which consist of a necessary correction for the finite velocity of the probe. Such a correction is non-trivial for the case of fast moving probes in compressible flow.

B. O. Johnson [7], researched on a Multi-Holed Pressure Probe Accuracy Analysis. A Cobra Probe is a four holed dynamic pressure probe that uses empirical relations to ascertain the local three velocity components and the total pressure of a flow at a

point. The aims of this thesis were to assess the accuracy of a newly acquired Cobra Probe (Series 100 manufactured by Turbulent Flow Instrumentation (TFI)) up to velocities of 90 m/s, develop a MATLAB graphical user interface (GUI) so as to analyse Cobra Probe data, and also to provide a detailed description of how to use and operate the probe in a closed-circuit ELD wind tunnel. TFI provides automated data acquisition and reduction software and claims the Cobra Probe output is accurate up to velocities of 90 m/s at pitch and yaw angles of ±45°. The measurements are said to generally be within ±0.5 m/s for velocity and ±1° for pitch and yaw measurements.

A.J. Pisasale, et al [8], He illustrated that a novel method for extending the calibration range of five-hole probe for highly three-dimensional flows. Five-hole probe following the non-nulling method to find unknown flow properties can only be used for a low range of acceptance angles due to singularity encountered in the calibration procedure. A novel method was adopted to extend this range so as to avoid singularity is then developed which allows calibration of a five-hole probe up to much larger values of pitch and yaw angles. The method has been tested using the experimental calibration data's of a five-hole probe that were obtained employing the 18in. × 18in. subsonic closed circuit wind tunnel of the University of New South Wales at the wind tunnel speed of 15 m/s.

III. METHODOLOGY

A. Design of 5 Hole Probe

A five hole probe is shown below. The probe is basically used for diagnostic wind tunnel testing and in flight testing to determine the flow direction or angularity. The probe is a group of five tubes; a center tube surrounded by four tubes in the shape of a cross. The leading edge of the four outside tubes is cut at a 45º angle to the center tube.

The flow of air past the probe makes an angle 'a' with the center-line of the center probe. If the angle was zero, all three probes would act as pitot tubes and transducers at the end of the tubes would measure the total pressure of the flow. If the angle is not equal to zero, the probe on the bottom detects a pressure p2 that is different than the pressure p1 on the top. The difference in values is caused by the dynamic pressure associated with the velocity of the flow. The difference in pressure between the top and bottom probes is some function of the angle of the flow:

$$PT – PB = f (a)$$

On calibrating the probe, we can determine the form of the function. The diagram at the left shows a vertical cut through three of the tubes. The angle of the flow 'a' is then related to the angle of attack in case of an aircraft. A similar type of horizontal cut can be made through the two remaining tubes and the angle of the flow is then related to the yaw angle of an aircraft. A five hole probe can hence be used to simultaneously provide the values of both pitch and yaw in a flight test, or to provide the flow angularity in two perpendicular planes in a wind tunnel test. Three hole probes can also be used if we are only interested in the flow deflection in one direction.

During a wind tunnel or flight test, the probe is inserted into the flow field and aligned relative to some part of the tunnel or aircraft. Using the measured values from the five tubes and the calibration curves, we can determine the deflection of the flow in two perpendicular planes in relation to the wind tunnel or aircraft part.

In some applications, the probe may be moved through the flow field to develop a complete map of the flow angularity. But in most of the applications, the probe is fixed to the tunnel wall, model, or flight vehicle.

The five hole pressure probe which is calibrated for the purpose of measuring the stagnation pressure. As the name implies, five-hole probes are characterized by five pressure sensing holes lying in a plane which is basically perpendicular to the other plane and the intersection of these two planes lays the central hole. The design specification of five hole probe is given below table 1.

Table 1: Design specification of five hole probe

SR. No	*Particular*	*Dimension*
1	*Diameter of Outside tube*	*6mm*
2	*Diameter of Inside tube*	*0.7mm*
3	*Total length*	*538mm*
4	*Numbers of inside tube*	*5*
5	*Head width*	*4.8mm*

The current probe has a spatial resolution of $2d$in both directions. Hence it can be used for highly three-dimensional flows such as flow in corner of blades and end wall flows with large pressure and velocity gradients in all directions. The L-shaped probe head details are shown in the figures above.

B. Fabrication of 5 Hole Probe

Design and fabrication specifications and the sizes of hypodermic tubes are given in Table 1. The probe material used is stainless steel hollow tubes. Tubes were purchased from Parry's corner in Chennai at the rates of Rs 100/-, Rs 75/- and Rs 50/- per metre length for 0.7mm, 1.6mm and 6mm diameter tubes respectively. The tubes were cut at required lengths as in figure using a triangular file and then cleared the faces using emery paper. Five tubes of 0.7 mm diameter are inserted into the tube of diameter 1.6mm. The 1.6mm tubes were carefully bend at 90° as shown in figure manually using a flat plate with a 1.6mm hole drilled in it. The tubes were inserted in the drilled hole and then bend at the required lengths which were marked in advance using a sharp pointed marker pen. These 5 tubes are inserted into a single hollow tube of diameter 6mm. To maintain the correct distance

between the end faces of the 1.6mm tubes, these were inserted into a flat plate which had 5 holes of 1.6mm diameter already drilled in it. After placing it in the required position, the gap between the inside and outside tube was filled with the araldite cladex solution at the proportion of 2:1, i.e., hardener: binder, which hence held the tubes firmly in proper position. The Probe has four ports equally spaced in a annular circular configuration around a central port. The outside holes are located on planes that are at 40ºangles with respect to the plane of the central hole, as shown in Figure 1. The geometry of the five hole probe is advantageous for use in aerofoil, turbo-machinery research which can be effortlessly inserted through casings which are used to detect the pressure at the surface of blades. Fig 1. Fabricated five hole probe with 90º bend.

1) Stem Section

The stem section comprises five 1.6mm diameter tubes of approximately 520mm length which are inserted into the other ends of the 0.7mm diameter tubes. Keeping the five tubes in the proper position and plane requires them to be pasted using here araldite cladex solution at different positions along its length. To maintain the position of the inner tubes fixed with respect to the stem, the outer tube of 5.8mm inner diameter and 6mm outer diameter is also pasted along with these tubes. This tube of 6mm outer diameter acts as the probe holder.

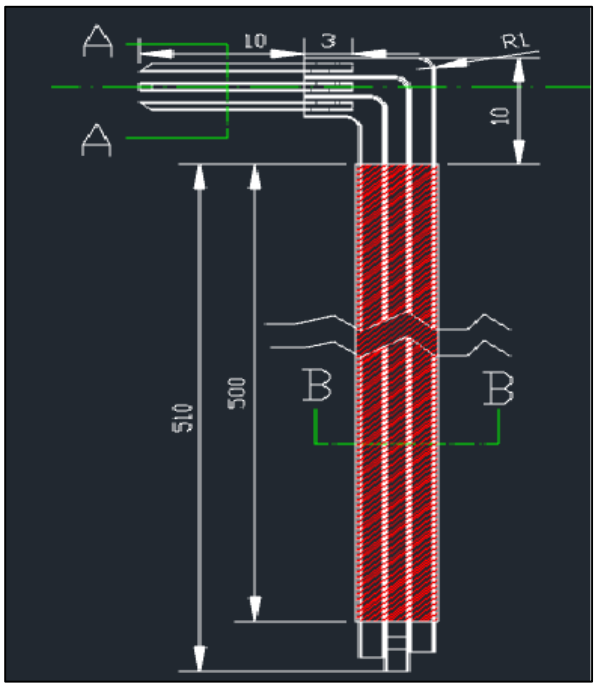

Fig. 1: 2D drawing of five hole probe

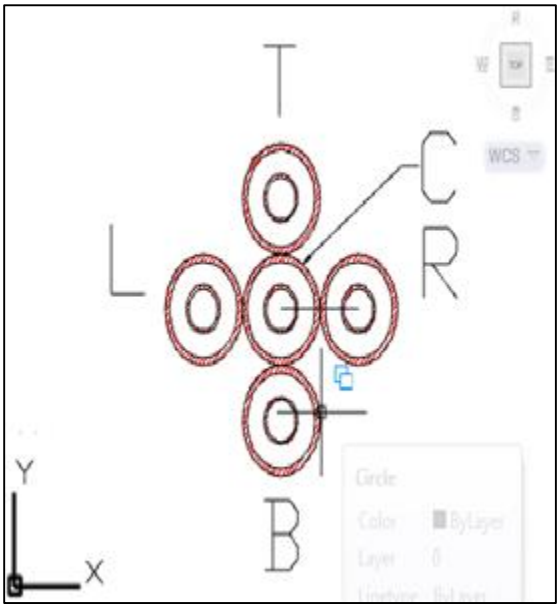

Fig. 2: Cross sectional view of probe holes

All dimensions are in mm

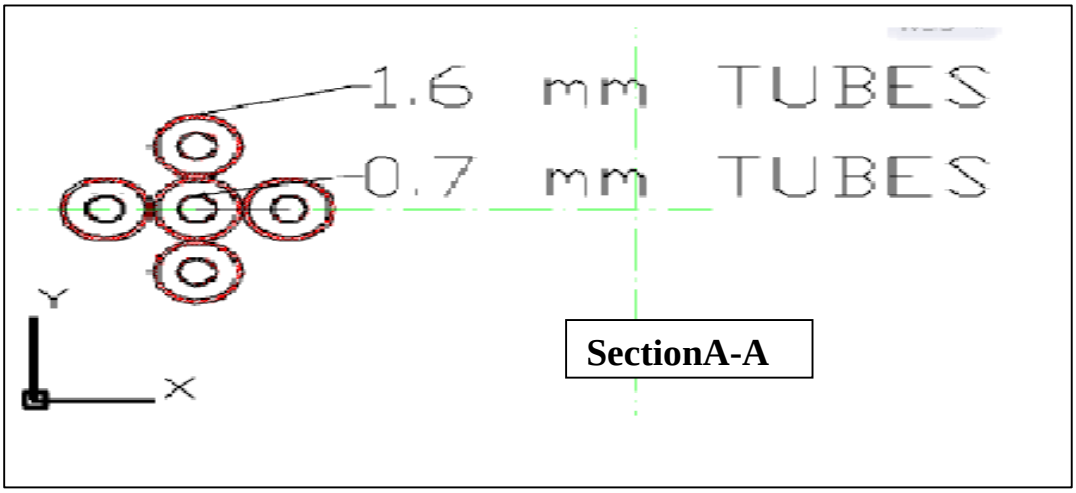

Fig. 3: Section A-A of probe hole diameters

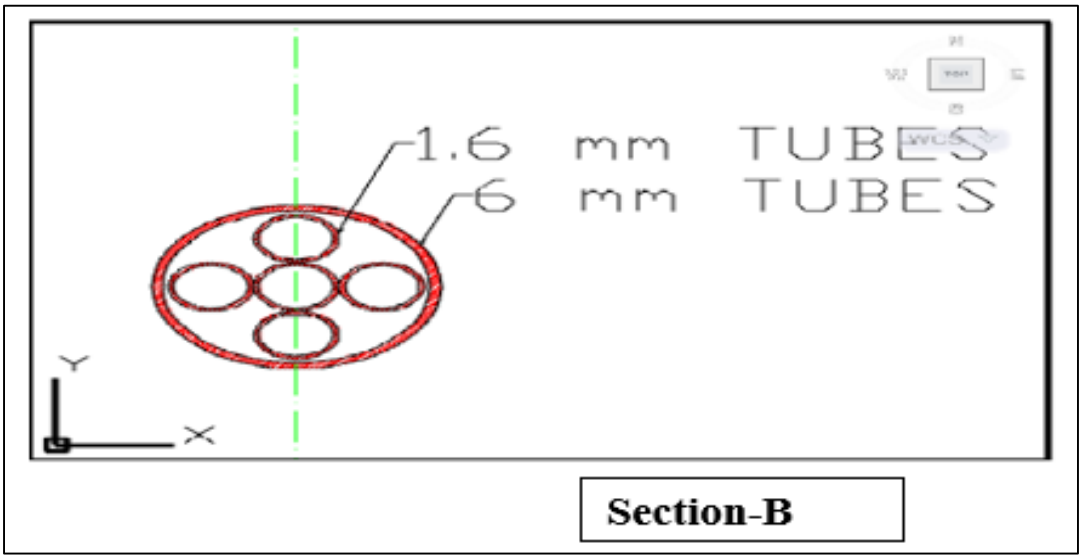

Fig. 4: Section B-B of probe hole diameters

Fig. 5: Fabricated and calibrate probe (Side View)

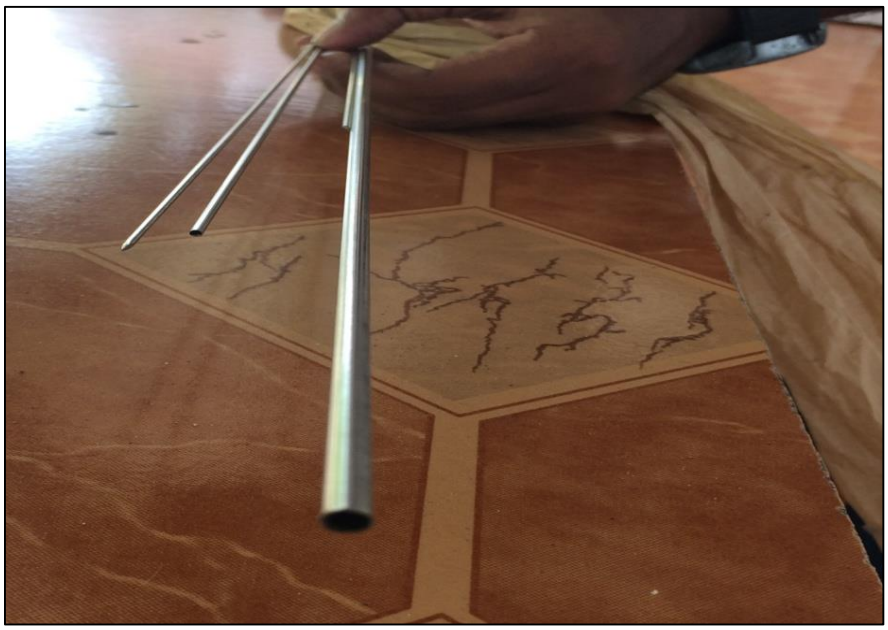

Fig. 6: Stainless steel tiubes used for manufacturing

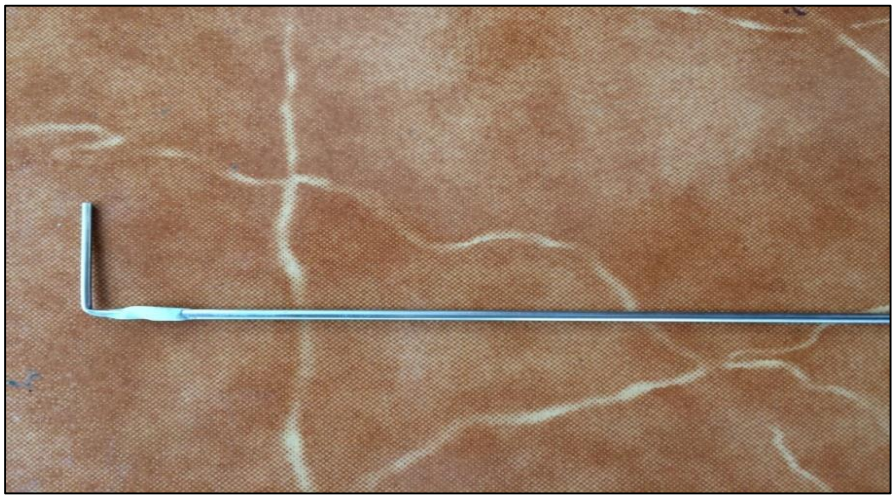

Fig. 7: Stainless steel tiubes(1 Nos of five tubes)

Fig. 8: Single tubes being inserted to a presdrilled flat plate to keep in position

Fig. 9: Tools and equipments used for fabrication

Fig. 10: Fabricated five hole probe

Fig. 11: Fabricated five hole probe tip

Fig. 12: Probe tips a close view

Fig. 13: Probe tips a close view under lens

IV. CALIBRATION PROCEDURE

The calibration process of the five-hole pressure probe was done on an open jet low speed calibration tunnel facility of Thermal Turbomachines Laboratory, Department of Mechanical Engineering, IIT Madras, were used for as shown in Figure 3. Calibration apparatus is made of base plate, *c*clamp, protractors, and pointers for measurement of pitch (β) and yaw (α) angles. The twenty-channel selection box FC 091 MKII and the FC 012 digital micro manometer with a range of 1–200mm of water and sensitivity of 0.1mm of differential air pressure are used to measure the probe pressures. The selection box was used in conjunction with the micro manometer to get the velocity and pressure readings.

Calibration of the probe is carried out at a known velocity of 50m/s. The probe is held on a probe holder with the help of sleeve so that the pressure sensing holes of the probe are to face the flow. The assembly of the probe and probe holder is kept 200mm away from the nozzle exit. Initially the zeroing of probe is done by setting up the pitch angle (β) to zero degree. Initially, after changing the yaw angle (α), set the position of the probe such that the pressure which is sensed by centre hole is maximum and the yaw angle corresponding to the maximum pressure sensed by the centre hole is noted down. Now the probe is rotated on both positive and negative sides of the yaw angle until the centre hole pressure is equal to half of the maximum pressure sensed and the corresponding values of yaw angles are noted down. The mean of the above measured yaw angles are taken as zero reference yaw angle. After fixing the zero reference position the probe is calibrated by changing $\alpha$and βin the range of −30°to 30° with an interval of 10°. The calibration is done by keeping (pitch angle) constant and by varying α(yaw angle). For every combination of $\alpha$and β, the probe pressures at the five ports are recorded.

A. Calibration Coefficients

The calibration coefficients are defined as follows:

$$C_{P\alpha} = \frac{P_T - P_B}{P_C - \overline{P}}$$

$$C_{P\beta} = \frac{P_R - P_L}{P_C - \overline{P}}$$

$$C_{PTOTAL} = \frac{P_C - P_{TOTAL}}{P_C - \overline{P}}$$

$$C_{PSTATIC} = \frac{\overline{P} - P_{STATIC}}{P_C - \overline{P}}$$

B. Calibration Curves

The calibration curves obtained as per conducting experiment are presented in Figure. For clear understanding, the so curves are indicated at intervals of 10° only.

The followings graphs are plotted:

1) Cp_{YAW} v/s Cp_{PITCH} for change in yaw and pitch angles.
2) Cp_{TOTAL} and Cp_{STATIC} contours with Cp_{PITCH} and Cp_{YAW} along the axis respectively.

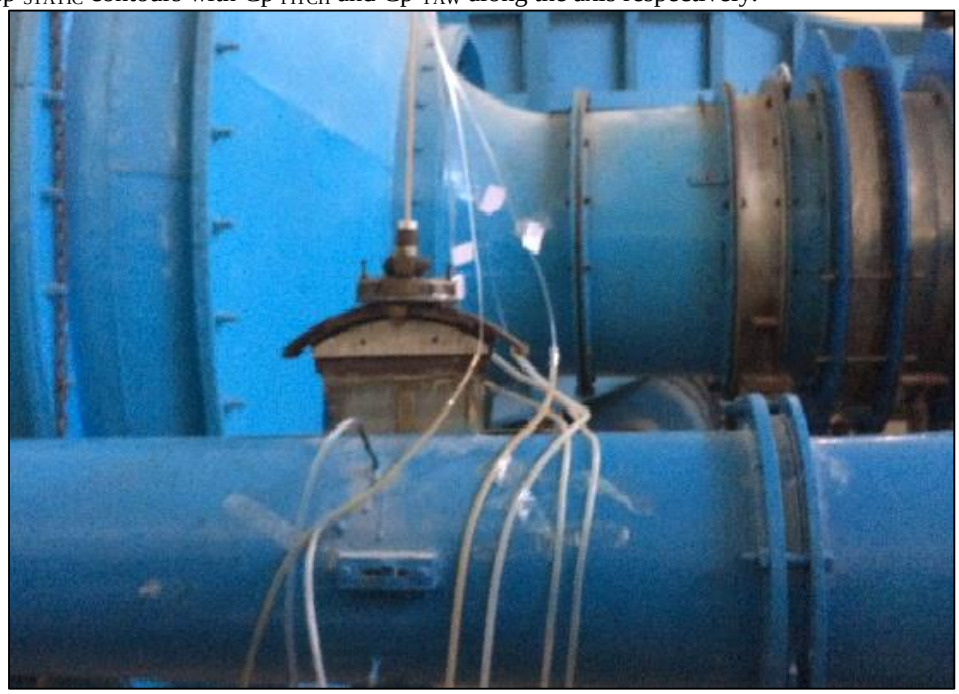

Fig. 14: Experimental setup used for calibration of a five hole probe (Pitch angle =0°)

Fig. 15: Experimental setup used for calibration of a five hole probe (Pitch angle =30°)

C. FC091 MKII Selection Box

Fig. 16: Selection Box used in calibration process

Scanning/Selection Boxes are used in conjunction with micro manometers, here which is FC012 Micro-manometer which is used to select/interchange between pressure ports of the 5 hole probe. It allows selecting a particular pressure port and hence measuring the pneumatic pressure in that port using the micro manometer.

D. FC012 Micro Manometer

Fig. 17: Micromanometer used for calibration process

The FCO12 high quality differential pressure micro manometer instrument has the characteristics of automatic zero. A function switch uses a square root extractor converting the instrument to an anemometer, measuring velocity in metres/sec. A small Pitot static tube is provided for this purpose. A variable response control allows the reading of fluctuating pressure and the output signal of 0-5VDC can be fed to data capture systems. The micro-manometers works on a capacitance differential pressure transducer of which measures differential pressures from .001pascal. Each instrument comprise of a differential pressure transducer, rechargeable battery pack, a readout meter (analogue or digital meter), a range switch and an equalizing valve. Where there is a multiple of pressure input, Furness Controls can supply Scanning Boxes for use in conjunction with micro manometers, here which is FC0 91 MKII.

V. RESULTS AND DISCUSSIONS

Calibration of multi hole probes are indicated by plotting graphs with least errors. Ideally, the graph should remain same every time the probe is calibrated. But there are many sources of errors. The prominent cause of errors in calibration is a sudden change in flow characteristics inside the calibration facility due to laboratory disturbances or unwanted air conditions during calibration process. Another source of error can occur when the probe is first aligned with the flow. The probe was initially aligned by hand and it leads to human error. In the calibration process, a FC 012 micro manometer was used to sample pressure from all five-pressure measurement points. Five tubes indicating the five hole probe ports and two other ports used as pitot probe, recorded the tunnel velocity, total pressure and static pressure in the test section. Thus errors at time of calibration are reduced to a great extent. The following values in table and graphs can be plotted using Equation 1 to Equation 4

Table 2: Calibration coefficients CpYAW and CpPITCH

PITCH (β)	YAW (α)								
	Degree		-30	-20	-10	0	10	20	30
	-30	Cp_{YAW}	-2.13	-0.62	0.899	2.377	5.63	13.36	68.57
		Cp_{PITCH}	-5.53	-5.14	-5.443	-6.192	-9.12	-16.03	-70.514
	-20	Cp_{YAW}	-1.573	-0.492	0.72	2.18	4.12	7.28	21.6
		Cp_{PITCH}	3.513	-3.19	-0.34	-4.1	-5.22	-6.78	-15.6
	-10	Cp_{YAW}	-1.67	-0.58	0.57	1.69	3.03	4.62	6.13
		Cp_{PITCH}	-2.11	-2.02	-2	-2.14	-2.34	-2.67	-3.3
	0	Cp_{YAW}	-1.58	-0.58	0.605	1.54	2.5	2.267	3.512
		Cp_{PITCH}	-0.475	-0.53	-0.507	-0.5025	-0.457	-0.55	-0.64
	10	Cp_{YAW}	-1.5	-0.33	0.719	1.68	2.79	3.473	3.12
		Cp_{PITCH}	1.23	1.081	1.033	1.132	1.06	1.009	0.6847
	20	Cp_{YAW}	-1.51	-0.153	0.969	2.193	3.43	4.48	5.162
		Cp_{PITCH}	3.22	2.5912	2.553	2.815	2.89	2.86	2.65
	30	Cp_{YAW}	-2.074	-0.331	1.044	2.289	3.77	5.262	6.98
		Cp_{PITCH}	5.111	4.13	3.954	4.16	4.84	5.38	5.43

Table 3: Calibration coefficients CpTOTALand CpSTATIC

PITCH (β)	YAW (α)								
	Degree		-30	-20	-10	0	10	20	30
	-30	Cp_{STATIC}	-0.44	-0.19	-0.17	-0.39	-1.186	-3.696	-24.25
		Cp_{TOTAL}	-1.77	-1.582	-1.77	-2.26	-4.328	-9.85	-54.97
	-20	Cp_{STATIC}	0.2522	0.3367	0.3633	0.278	-0.14	-1.3948	-5.197
		Cp_{TOTAL}	-0.705	-0.532	-0.633	-1.094	-2.123	-3.987	-14.17
	-10	Cp_{STATIC}	0.5463	0.6597	0.702	0.5868	0.2702	-0.52727	-1.641
		Cp_{TOTAL}	-0.2913	-0.122	-0.132	-0.3402	-0.8725	-1.77	-3.0973
	0	Cp_{STATIC}	0.7689	0.9195	0.933	0.745	0.305	-0.345	-0.8753
		Cp_{TOTAL}	-0.145	-0.0209	-0.0211	-0.114	-0.457	-0.76	-1.35
	10	Cp_{STATIC}	0.733	0.8268	0.8115	0.7389	0.3415	-0.2476	-0.77
		Cp_{TOTAL}	-0.33	-0.134	-0.1256	-0.3014	-0.623	-1.009	-1.076
	20	Cp_{STATIC}	0.5597	0.56534	0.51923	0.4327	-0.0166	-0.6216	-1.478
		Cp_{TOTAL}	-1.04	-0.68	-0.6153	-0.899	-1.319	-1.929	-2.748
	30	Cp_{STATIC}	0.0945	0.3015	0.2147	0.0233	-0.4873	-1.166	-2.293
		Cp_{TOTAL}	-2.086	-1.487	-1.35	-1.57	-2.3	-3.2901	-4.83

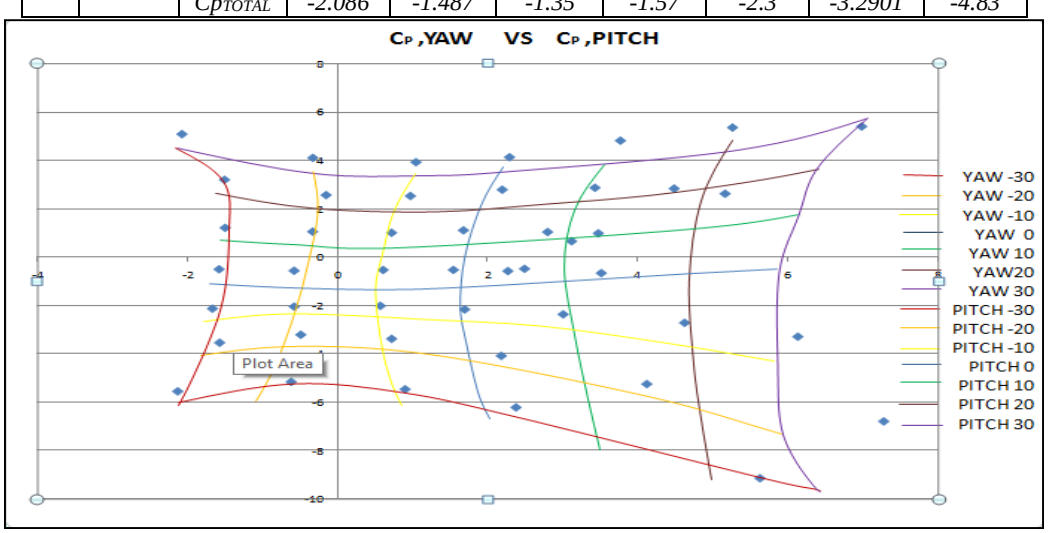

Fig. 18: CPYAW v/s CPPITCH

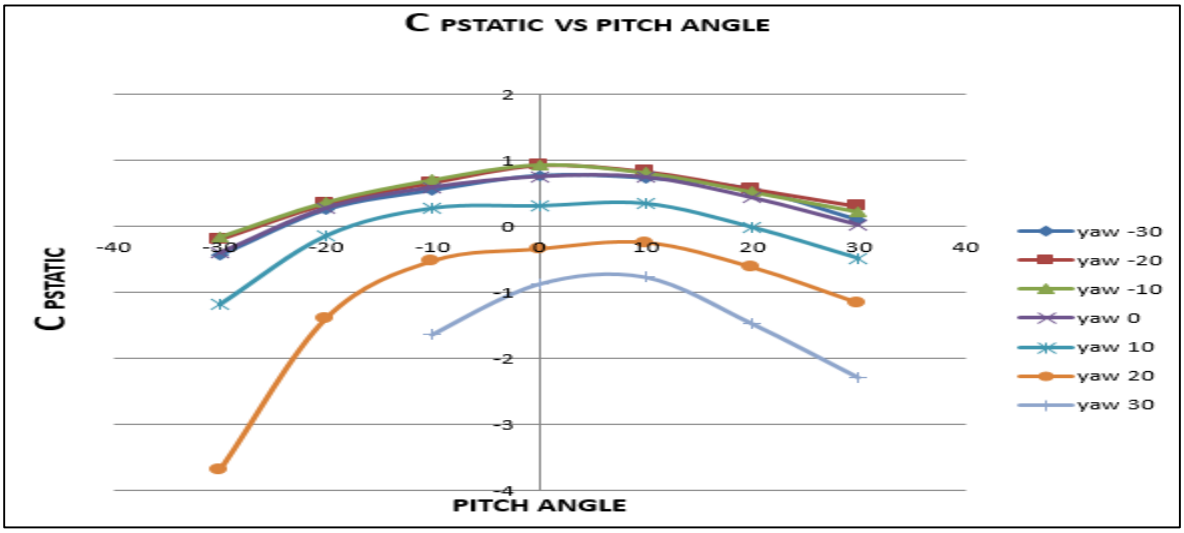

Fig. 19: CPSTATIC v/s Pitch Angle

Figure 18 shows that the center of the curves indicates the average value and the four points surrounding each curve indicates the data individually collected from each run. Almost all points in the range of ±20° resembles/closes the average value. The areas lying outside to this range, those greater than ±20°, that the blocks start to get diverging and errors, such as a misalignment start becomes more pronounced. The grid map formed and as shown in Figure is not perfectly symmetrical because a dimensionally symmetric and accurate five-hole probe is very difficult to obtain during the even the best precision hand manufacturing process employed. Figure 18shows a typical averaged carpet map produced by readings obtained by the probe. This grid map is used for finding the best suitable range of pitch and yaw angles during a five-hole probe measurement. From the figure it is observed that the best range of yaw and pitch angle for measurement of probe is ±20°.

Figure 19 shows the relation between total pressure coefficient with respect to pitch angle and yaw angle. Total pressure coefficient can be obtained from Figure by using the pitch and yaw angle deduced from Figure. It is seen that total pressure coefficient increases initially with pitch angle and after certain value of pitch angle it decreases for each value of yaw angle combination.

The next figure gives the static pressure coefficient as a function of pitches and yaw angle. Local static pressure from the five-hole probe measurement can easily be recovered from Figure after determining the pitch and yaw angle. The nature of the graph shows that static pressure coefficient increases initially with pitch angle. It reaches to a higher value and then decreases.

VI. CONCLUSIONS

This work, mainly deals with the fabrication and hence calibration of probe. The calibration of the probe was carried out in an open jet type of wind tunnel. In wind tunnel calibration, it was found that the probe gives the correct readings at the centre position of test section. At the centre, the flow is fully developed. Boundary layer phenomenon predominates at the wall ends and hence probe was not tested at such location. The probe used for calibration was tested for different positions of yaw and pitch angle. From the results as stated above, it can be said that the best suitable range of yaw and pitch angle for the measurements of pressure is +30º to -30º.

A. Nomenclature

C_{PPITCH}	Pitch coefficient
$C_{PSTATIC}$	Static pressure coefficient
C_{PTOTAL}	Total pressure coefficient
C_{PYAW}	Yaw coefficient
P_B	Pressure sensed by bottom hole (mm of H_2O)
P_C	Pressure sensed by centre hole (mm of H_2O)
$\overline{P}$	Average pressure sensed by chamfered holes (defined in text)
P_{TOTAL}	Total Pressure (mm of H_2O)
P_R	Pressure sensed by right hole (mm of H_2O)
P_L	Pressure sensed by left hole (mm of H_2O)
P_{STATIC}	Static Pressure (mm of H_2O)
P_T	Pressure sensed by top hole (mm of H_2O)
r	Radius of calibration section (m)
V	Velocity in the calibration section (m/s)

V_C	Velocity at the centre of the calibration section (m/s)
y	Distance from the wall of the calibration section (m)
α	Yaw angle (deg.)
β	Pitch angle (deg.)

VII. CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest regarding the publication of this paper.

ACKNOWLEDGMENT

The authors would like to thank Dr.Govardhan M, Professor in Department of Mechanical engineering for granting permission to conduct calibration process in the wind tunnel setup in Thermal Turbo machines Laboratory, and IIT Madras. Also we would like to thank Mr. N. Giri & Mr. M. Veeraraghavan of Thermal Turbo machines Laboratory, Department of Mechanical Engineering, IIT Madras, for explaining us on the experimental setup and for their co-operation. The authors would like to thank the reviewers for their suggestions, which improved the quality of the paper substantially.

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