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Experimental Investigation of Conical Flow Meter for Truth-Flow Analysis of Wind Tunnel

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Abstract: Aerodynamic world relies on experimentation and obtaining practical results to solve complex real-life problems. The airflow characteristics are examined under different situations in aerodynamics, which allows for the solution of many real-life difficult problems. Although mathematical theoretical notions are developed to handle complex issues, they cannot be regarded as a credible source. As a result, finding experimental validation of those difficult challenges is critical. In most cases, the aerodynamic tool used to study the flow and its related characteristic is a wind tunnel. Wind tunnels generally explain the flow behavior over different bodies. But before performing experimentations with a wind tunnel, calibration needs to be carried out. In this paper, a five-probe conical flow meter has been used to ensure the truth flow inside a subsonic wind tunnel.

Keywords: Calibration: Flow Meter; Computational Fluid Dynamics; Wind tunnel

1. Introduction

Wind tunnel testing has been carried out for years Testing flow quality in wind tunnels, a crucial activity in experimental aerodynamics, entails a variety of techniques and the use of cutting-edge technology[1]. One of the most essential characteristics of flow quality is velocity[2]. For high-quality findings in wind tunnel experiments, high quality flow oriented in uniform manner along with appropriate measurement techniques are most essential[3]. The measurement of flow velocity in aerodynamic tests generally uses a mix of probes and transducers to assess stagnation and static pressure[4].

The fluid flow rate, and efficiency are commonly measured data in hydraulic machine experiments.[5] These quantities provide a worldwide description of the hydraulic function over the machine's operating range, i.e. efficiency values for certain flow rate, specific energy, and cavitation coefficient circumstances.[6]The measure of unstable velocity and pressure fields are required for thorough investigations of hydrodynamic dynamics.[7] The inclusion of embedded sensors in the probe head has eliminated this inconvenience, resulting in erratic pressure measurements[8].In combustion chambers, swirling jets are employed to regulate flames[9]. The presence of a swirl causes the formation of radial and axial pressure gradients, which influence flow fields[10]. To navigate safely and successfully in the air, air vehicles require correct air data information[11]. To complete complex tasks, helicopters are frequently put in extreme motion including the high angle of attack[12].

Other than the vehicle's longitudinal axis, certain jet-engine aircraft are designed to be able to direct engine thrust in numerous directions[13]. Control surfaces are still used to manipulate thrust vectoring aircraft, although to a lesser extent. To maintain and regulate the flight path, most aircraft require movable control surfaces[14]. Pitch, roll, and yaw are the three moments operating on an airplane, and these surfaces are utilized to adjust them. Because the measurement of airflow angles and real airspeed is so crucial to the turbulent wind vector and all turbulent flux measurements, a thorough examination of the system faults and sources of noise in MHP measurements will be carried out[15].

The types and performance of fast response aerodynamic probe devices used to investigate turbo machinery flows, as well as examples of their use[16]. One, two, or more pressure sensors are commonly included in the probe tip of probes designed for turbo equipment[17]. Pressure probes are instruments casted to determine the velocity and pressure of a fluid flow in a variety of research and industrial applications[18].

Unsteady pressure measurements are used in research, condition monitoring, and maintenance. Miniature transducers are used to measure the pressure distribution on rotor blades[19]. The rotor exit flow is inspected using probes equipped with small pressure transducers, which provide detailed information on the 2D or 3D flow field, including velocities and pressure distribution. Three-hole and five-hole probes typically have an angular range of roughly 30°, which is sufficient for a wide range of applications[20].

There are many types of probes and mainly they are designed based on the application field. Multi-hole Probes, High-Temperature Probes are a few among them[21]. A standard probe has a single cylindrical body with five or seven holes at the tip. Within pressure-sensing equipment, the holes are connected. When the probe is in the flow, velocity magnitude and direction concerning the probe based on the pressures measured from each port can be obtained[22]. A homogenous, regular steady water flow within a closed channel, as well as the dimensionless pressure portions corresponding to various probe angles, are required for calibration. The calibration curve represents a field's well-known pressure distribution[23].

The benefits of a multi-function probe are its simple structure and ability to provide a variety of data such as static and total pressure, speed, pitches, and yaw angles. As a result, the Multi-Function Probe may be used to investigate three-dimensional fluid flows[24]. Wind tunnels comprise an entry section termed a convergent cone, followed by the test section and an exit section called a divergent duct or diffuser. The models or test specimens will be placed in the test section for studying the flow behavior over it. In the test section, before conducting any experiments it has to be made to zero turbulent flow, which is practically not possible. For low-speed tunnels, in most cases, a honeycomb section is used for the same. In a few cases, even settling chambers are installed to verify the inlet flow. Though it is impossible to make the flow fully laminar. hence inside the test section of each wind tunnel, there exist flow angularities. Normally a pitot-static tube/probe is used to predict the flow angularity in the test section. But it has been proven that the data obtained using a pitot-static tube/ probe is not reliable. Hence a five-probe conical flow meter has been designed, fabricated, and tested to determine the flow angularity[25].

2. Methodology

A five-probe conical flow meter has been designed and fabricated. The fabricated flow meter is shown in Figure 1. There are 25 pressure tapings equally distributed on five conical probes[2]. The conical flow meter is designed with a semi-cone angle of 200 and a frontal area of 3975 mm^2.

The designed five probes conical flow meter has been mounted in a subsonic wind tunnel test facility available at Aerozjet Aviation with a test section size of 300 x 300 mm. The tunnel blockage factor has been determined and is equal to 4.42. The testing has been conducted on a day when the average room temperature was recorded as 308.2 K. The instrument has been tested at a velocity of 17.15m/s which is equal to Mach Number 0.05 and the corresponding theoretical parameters such as dynamic pressure, stagnation pressure and static pressure has been obtained as in Table 1[2].

Table 1. Theoretical parameters at 308.2 K

Velocity	Dynamic Pressure	Stagnation Pressure	Static Pressure
m/s	Pa	Pa	Pa
17.15	180.1500313	108582.5969	108402.4469

Fig. 1: Fabricated Five-Hole Five-Probe Flow Analyzer

The first position is located with the coordinate of the center hole at (100,150,100) and readings have been taken with a flow velocity of 17.15 m/s in the test section. The obtained values of pressure at each of the twenty-five holes are recorded in Table 2.

Table 2. Pressure readings at location 1

Probe	Hole	Pressure
		Pa
Probe A	1	108143.9
	2	108143.1
	3	108143.1
	4	108143.3
	5	108142.9
Probe B	6	108143.3
	7	108143.1
	8	108143
	9	108143
	10	108143.2
Probe C	11	108142.9
	12	108142.9
	13	108143.1
	14	108143
	15	108143.4
Probe D	16	108143.2
	17	108143.6
	18	108143.1
	19	108143.8
	20	108143.8
Probe E	21	108143.4
	22	108143.4
	23	108143.8
	24	108143.3
	25	108143.5

The second position is located with the coordinate of the center hole at (100,150,125) and readings have been taken with a flow velocity of 17.15 m/s in the test section. The obtained values of pressure at each of the twenty-five holes are recorded in Table 3

Table 3. Pressure readings at location 2

Probe	Hole	Pressure
		Pa
Probe A	1	108143.7
	2	108143.1
	3	108143
	4	108143.4
	5	108143
Probe B	6	108143.4
	7	108143.1
	8	108143.1
	9	108143.5
	10	108143.5
Probe C	11	108143.6
	12	108143.4
	13	108143.1
	14	108143.5
	15	108143.5
Probe D	16	108143.2
	17	108143.6
	18	108143.1
	19	108143.1
	20	108143.6
Probe E	21	108142.8
	22	108143
	23	108143.6
	24	108143
	25	108142.9

The third position is located with the coordinate of the center hole at (100,150,150) and readings have been taken with a flow velocity of 17.15 m/s in the test section. The obtained values of pressure at each of the twenty-five holes are recorded in Table 4.

Table 4. Pressure readings at location 3

Probe	Hole	Pressure
		Pa
Probe A	1	108143.9
	2	108143.1
	3	108143.1
	4	108143.3
	5	108142.9
Probe B	6	108143.3
	7	108143.1
	8	108143
	9	108143
	10	108143.2
Probe C	11	108142.9
	12	108142.9
	13	108143.1
	14	108143
	15	108143.4
Probe D	16	108143.2
	17	108143.6
	18	108143.1
	19	108143.8
	20	108143.8
Probe E	21	108143.4
	22	108143.4
	23	108143.8
	24	108143.3
	25	108143.5

The fourth position is located with the coordinate of the center hole at (100,150,175) and readings have been taken with a flow velocity of 17.15 m/s in the test section. The obtained values of pressure at each of the twenty-five holes are recorded in Table 5.

Table 5. Pressure readings at location 4

Probe	Hole	Pressure
		Pa
Probe A	1	108143.4
	2	108143
	3	108143.5
	4	108143.2
	5	108143.6
Probe B	6	108143.8
	7	108142.8
	8	108143.1
	9	108142.9
	10	108143
Probe C	11	108143.4
	12	108143.7
	13	108143.4
	14	108142.9
	15	108143.8
Probe D	16	108143.5
	17	108142.9
	18	108143.6
	19	108143.2
	20	108143.8
Probe E	21	108142.9
	22	108143.7
	23	108143.1
	24	108143.7
	25	108143.4

The fifth position is located with the coordinate of the center hole at (100,150,200) and readings have been taken with a flow velocity of 17.15 m/s in the test section. The obtained values of pressure at each of the twenty-five holes are recorded in Table 6.

Table 6. Pressure readings at location 5

Probe	Hole	Pressure Pa
Probe A	1	108143.9
	2	108143.1
	3	108143.1
	4	108143.3
	5	108142.9
Probe B	6	108143.3
	7	108143.1
	8	108143
	9	108143
	10	108143.2
Probe C	11	108142.9
	12	108142.9
	13	108143.1
	14	108143
	15	108143.4
Probe D	16	108143.2
	17	108143.6
	18	108143.1
	19	108143.8
	20	108143.8
Probe E	21	108143.4
	22	108143.4
	23	108143.8
	24	108143.3
	25	108143.5

To substantiate the experimental pressure values so obtained using a flow analyzer at 17.15 m/s, a conventional pitot-static probe has been used at all the twenty-five locations and pressure readings have been determined at 308.2 K and charted as in Table 7.

Table 7. Pressure readings from the pitot-static probe

Position	Static Pressure Values *(Pa)*	Stagnation Pressure Values *(Pa)*
Position 1	108243.6	108342.9
Position 2	108243.1	108343.3
Position 3	108243.3	108343.5
Position 4	108243.2	108343.8
Position 5	108243.7	108343.2
Position 6	108243.4	108343.8
Position 7	108243.2	108343.8
Position 8	108243.3	108343.3
Position 9	108243.3	108343
Position 10	108243.4	108343
Position 11	108243.2	108342.9
Position 12	108243	108343.6
Position 13	108243.5	108343.1
Position 14	108243.8	108343.3
Position 15	108243.1	108343.1
Position 16	108243.7	108343.2
Position 17	108243.4	108342.9
Position 18	108243	108343.3
Position 19	108243.4	108343.2
Position 20	108243.5	108343.1
Position 21	108243.2	108343.5
Position 22	108243	108343.1
Position 23	108242.9	108343.4
Position 24	108243	108343.7
Position 25	108243.4	108343

3. Results and Discussion

The pressure readings obtained in Table 2 to Table 6 during experimentation have been compared with the theoretical results obtained in Table1. It has been noted that the average error percentage obtained is about 0.793 when comparing the experimental and theoretical results for flow velocity 17.15 m/s.

To represent the extend of pressure fluctuations inside the tunnel and to evaluate the truth-flow of the tunnel, pressure grid has been generated at the selected five locations. Pressure distribution grid has been obtained as in Figure 2 for flow velocity 17.15 m/s at position 1.

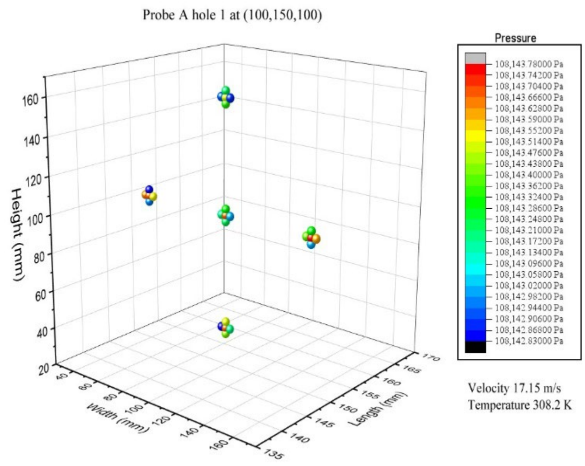

Fig. 2: Pressure distribution grid for flow velocity 17.15 m/s at position 1

The pressure distribution grid has been obtained as in Figure 3 at a flow velocity of 17.15 m/s at position 3.

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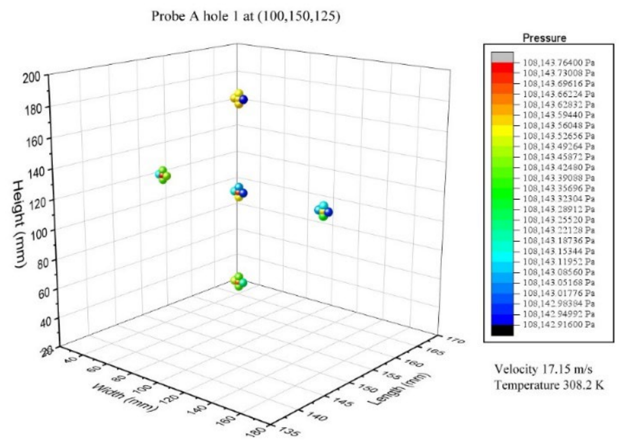

Fig. 3: Pressure distribution grid for flow velocity 17.15 m/s at position 2

The pressure distribution grid has been obtained as in Figure 4 for flow velocity 17.15 m/s at position 3.

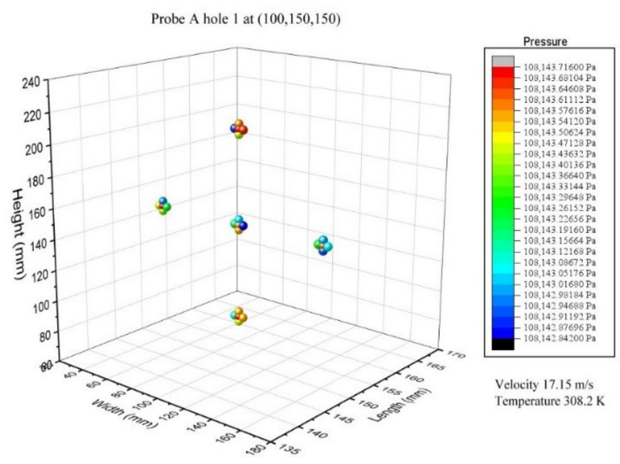

Fig. 4: Pressure distribution grid for flow velocity 17.15 m/s at position 3

The pressure distribution grid has been obtained as in Figure 5 for flow velocity of 17.15 m/s at position 4.

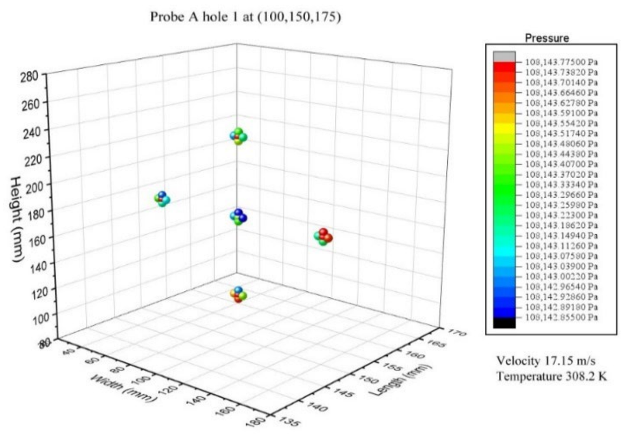

Fig. 5: Pressure distribution grid for flow velocity 17.15 m/s at position 4

The pressure distribution grid has been obtained as in Figure 6 for flow velocity 17.15 m/s at position 5.

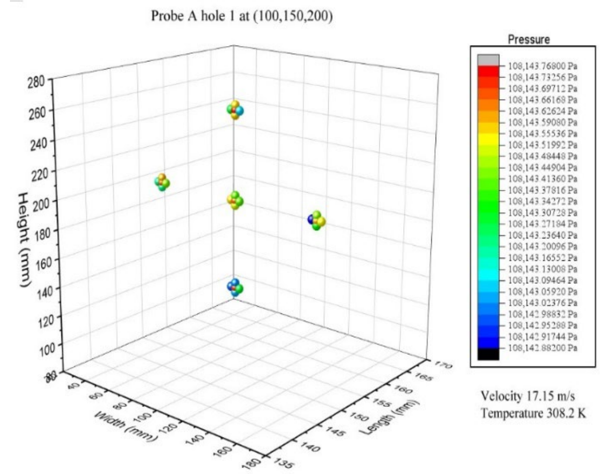

Fig. 6: Pressure distribution grid for flow velocity 17.15 m/s at position 5

From the values obtained from the flow meter, the average experimental stagnation pressure is 108143.38 Pa and the static pressure value is 108142.5 Pa. With a conventional pitot-static probe, the average experimental stagnation pressure value is 108343.27 Pa and the static pressure value is 108243.3 Pa. From these values obtained, the average error percentage between the flow analyzer and the conventional pitot-static probe is 0.184 for stagnation pressure and 0.09 for static pressure. This proves that the efficiency of the five-hole five probe flow analyzer is highly exemptional to determine stagnation and static pressure distribution.

Figure 7 represents the experimental results of the flow meter in the test section of AEROZJET at the subsonic condition at 308.2 K. The graph is plotted between different Mach Numbers and the distance of the probe in the test section.

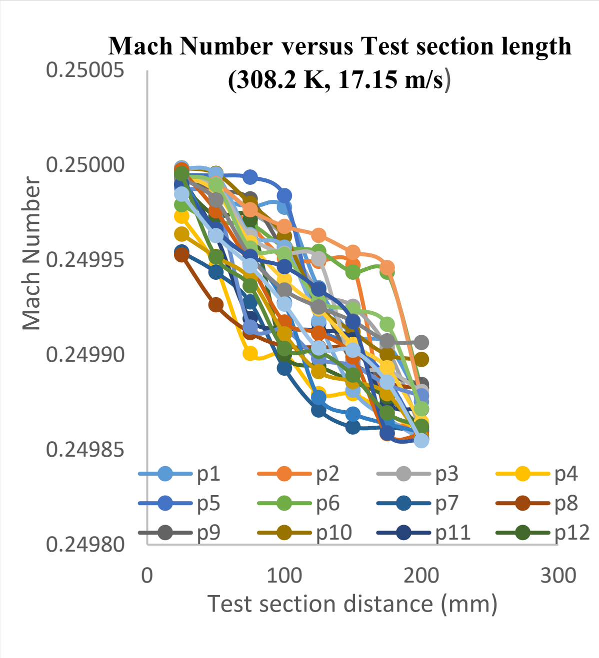

Fig 7: Graph for Test Section distance vs Mach number

4. Conclusion

The flow meter has been subjected to testing and validation in a low-speed, subsonic wind tunnel test facility. The results obtained during the testing matched well with the results recorded using a conventional pitot-static probe. Also, the comparison between theoretical results and experimental results shows very less deviations, making the error percentage so less, 0.184% for stagnation pressure and 0.09% for static pressure. From the results obtained and the comparison procedure, it can be concluded that the flow meter can be used for calibration of subsonic wind tunnel test facility and in truth flow analysis of wind tunnels.

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Nomenclature

m/s	Meter per second
Pa	Pascal
K	Kelvin

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