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Comparative study on performance accuracy of three probe and five probe flow analysers for wind tunnel testing

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Cover Page Footnote

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In fluid flow studies, experimentation can be done in three ways, namely Direct Measurement, Analogue Measurement, and Flow Visualization. In major cases, experimentation in direct method is achieved through wind tunnel studies. Wind tunnels are the ducts that allow the flow of air in axial direction over an object placed in the test section that has to be examined. For large number of investigations in aerodynamics, wind tunnels are used as the basic tool. For performing fundamental research activities to very high industrial aerodynamic problems, researchers rely on wind tunnel test set up (Lien & Ahmed, 2011). For most cases, determining the forces acting on any required objects such as lift and drag, the models will be scaled down. Many parts of aircraft, an aircraft itself, building structures, reservoirs etc. are scaled down so as to conduct studies on it in wind tunnel.

Generally, forces such as drag and lift obey similarity law given by

$$F = \frac{1}{2}\rho V^2 S C_N \qquad (1)$$

The data obtained by wind tunnel experimentation is correlated using various instruments. For validating velocity obtained during experimentation, hot wire anemometer, Lase Doppler Anemometer, pitot-static tubes, etc., are used. In the same way, fluid thermometers and pyrometers can be used for correlating temperature. Instruments like manometers, pressure gauges, and pressure transducers can be used for pressure validation (Yasar & Melda, 2011). The forces and moments are validated using specially designed wind tunnel balances or existing balances such as wire, struct, or pyramid balances. Density validation can be done using the measured pressure and temperature (Main et al., 2016).

Methodology

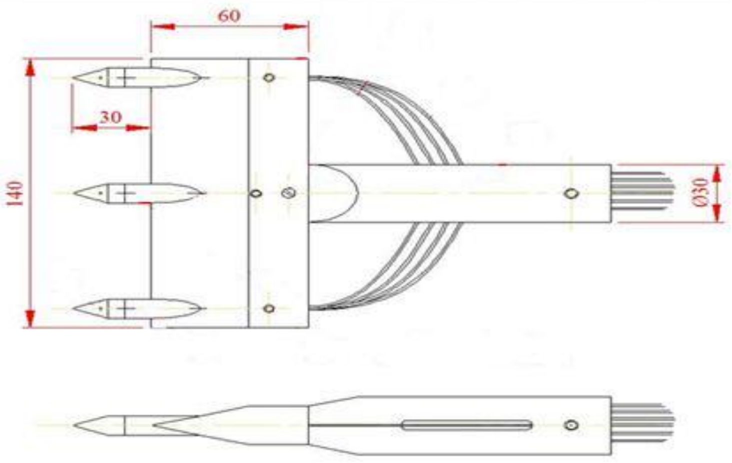
To conduct experimentation with wind tunnels, the tunnels need to be calibrated first. Generally, for a subsonic wind tunnel, the process of calibration is conducted with a pitot static probe. But the result so obtained cannot be sufficient to perform complete analysis of the tunnel. Hence two different instruments have been designed and tested in a wind tunnel facility available at Aerozjet Aviation, India. The instruments are three probe flow analyser and five probe flow analysers.

Design of the Probe

Three Probe Flow Analysers

The three-probe flow analyser has a total of 12 holes spreading with equal spacing on the three probes. Each probe has 4 holes spaced at 22.5 degrees on the circumference of the probe hole at a distance of 10.3 mm from the tip. The total length of the instrument is 145 mm and the three probes are fixed on a wedge of 140 mm with equal gap between them. The semi cone angle of the probe is selected using θ-β-M relation. The lesser the apex angle of the cone, wider the range of Mach over which a smooth pressure values can be obtained (Rupesh & Muruga lal Jeyan, 2020). Also, the sensitivity of the instrument increases with increase in angle of the cone. Hence it is noted from the obtained results that semi-cone angle of 20 degrees can best suited to satisfy the requirement of a supersonic tunnel. The shock wave generated for Mach 3.0 is nearly 29.3^0 which is almost approaching near to the periphery of the instrument. Hence according to the theoretical calculation, it can be concluded that the instrument can be used for up to a Mach Number of 3.0 (Rupesh & Muruga lal Jeyan, 2020). The three-probe flow analyser has been designed as per the specific dimensions and assembled as in Figure 1. The adapter is connected with the wedge which comprises the cone probe with the cone adapter (Muruga lal Jeyan et al., 2014).

Figure 1
Three Probe Flow Analyser (Muruga lal Jeyan et al., 2014)

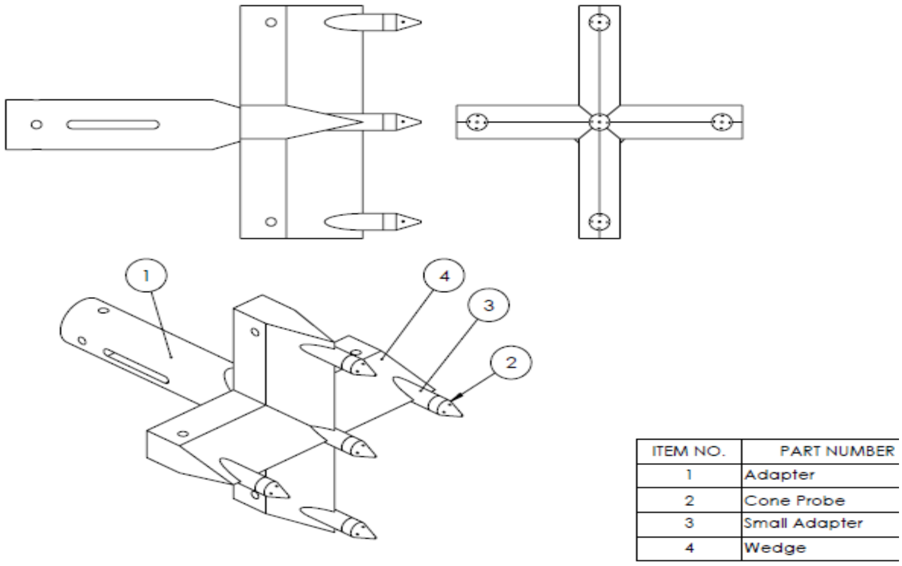


Five-Probe Flow Analyser

The five-probe flow analyser consist of two equally spaced probe both in vertical and horizontal wedge from the central probe. In this instrument, each probe has five holes as shown in Figure 2 (Rupesh & Muruga lal Jeyan, 2020).

Figure 2

Five Probe Flow Analyser (Rupesh & Muruga lal Jeyan, 2020)



Result and Discussion

Both the instruments have been mounted in the wind tunnel with test section of 300 x 300 mm x 300 mm cross sectional area. The wind tunnel considered for experimentation is a subsonic open circuit, suction type wind tunnel with a contraction ratio 9:1. The process involves alignment of the instrument in the wind tunnel at a measured distance in the test section. Initially five points have been identified inside the test section to fix the instruments for testing. It is made definite that the longitudinal axis and the axis of the instrument are parallel to each other. This is again elucidated by the readings on the manometer being the same. The angle between the axis of the flow analyser and the axis of the wind tunnel gives us the inclination Ψ measured in degrees. The pressure measurements are recorded at each successive inclination of the instrument. Simultaneously a pitot static tube connected to a sensor is use to find the dynamic pressure of the flow.

At 35.05^{o}C, instruments have been subjected to experimentation in the same tunnel at all the predefined five points with various velocities. The values obtained for both the instruments have been charted out. For reference the values obtained at Mach 0.2 has been tabulated for both the instruments. The theoretical values corresponding to the defined temperature and velocity conditions are tabulated as in Table 1.

Table 1

Theoretical Values of Flow Parameters at 35.05º C

Mach No	Velocity *(m/s)*	Dynamic Pressure *(Pa)*	Stagnation Temperature *(K)*	Stagnation Pressure *(Pa)*	Static Pressure *(Pa)*
0.2	68.8	2899.232	311.0525927	109358.3153	106459.08

The five-probe flow analyser has been mounted in the wind tunnel test section and pressure readings have been recorded in Table 2.

Table 2

Pressure Values for Five Probe Flow Analyser at Temperature 35.05º C and Velocity 68.8m/s for Position 1

		Width(X) mm	**Length(Y) mm**	**Height(Z) mm**	**Pressure Pa**
Probe A	Hole 1	100	150	100	105987.05
	Hole 2	96.8	150	100	105986.91
	Hole 3	103.2	150	100	105986.65
	Hole 4	100	150	103.2	105986.65
	Hole 5	100	150	96.8	105986.77
Probe B	Hole 6	160	150	100	105987.01
	Hole 7	156.8	150	100	105986.68
	Hole 8	163.2	150	100	105986.83
	Hole 9	160	150	103.2	105986.94
	Hole 10	160	150	96.8	105986.60
Probe C	Hole 11	40	150	100	105987.04
	Hole 12	36.8	150	100	105986.78
	Hole 13	43.2	150	100	105986.84
	Hole 14	40	150	103.2	105986.63
	Hole 15	40	150	96.8	105986.85
Probe D	Hole 16	100	150	40	105986.94
	Hole 17	96.8	150	40	105986.80
	Hole 18	103.2	150	40	105986.73
	Hole 19	100	150	43.2	105986.87
	Hole 20	100	150	36.8	105986.79
Probe E	Hole 21	100	150	160	105987.03
	Hole 22	96.8	150	160	105986.92
	Hole 23	103.2	150	160	105986.67
	Hole 24	100	150	163.2	105986.86
	Hole 25	100	150	156.8	105986.69

The five probe flow flow analyser has been mounted at various positions, keeping Probe A co-ordinate as reference and pressure values were noted. With the values so obtained, pressure graphs are plotted as shown in figures 3, 4, 5, and 6 . These plotted pressure values forms a grid representation which serves as a very efficient tool in performing high end research activities with the wind tunnel.

Figure 3

Grid Wise Representation of Pressure Values for Reference Point (100,150,125)

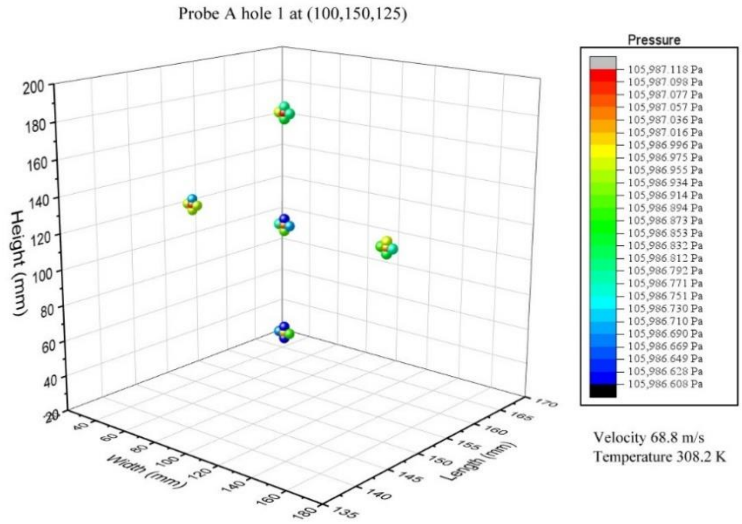


Figure 4

Grid Wise Representation of Pressure Values for Reference Point (100,150,150)

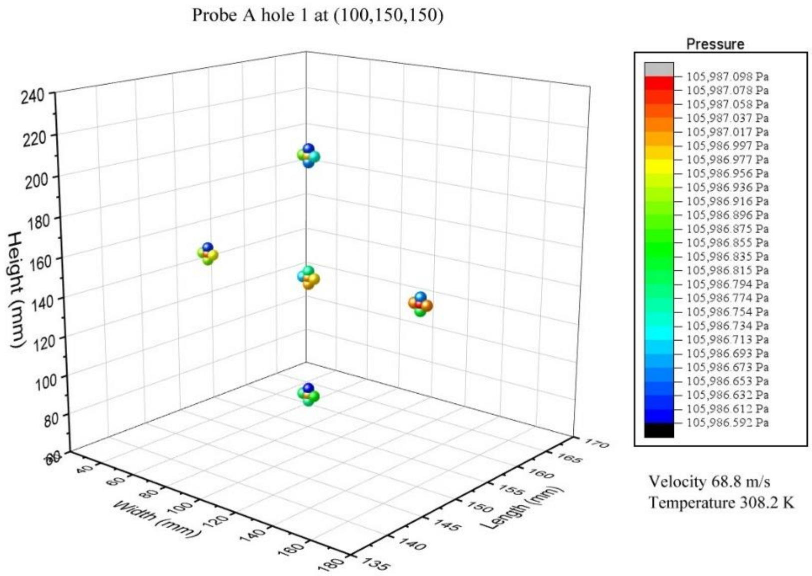


Figure 5

Grid Wise Representation of Pressure Values for Reference Point (100,150,175)

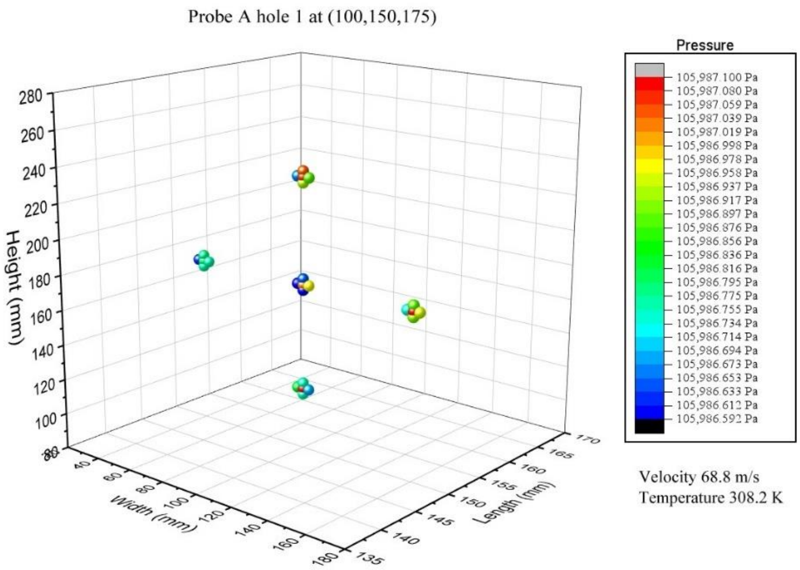
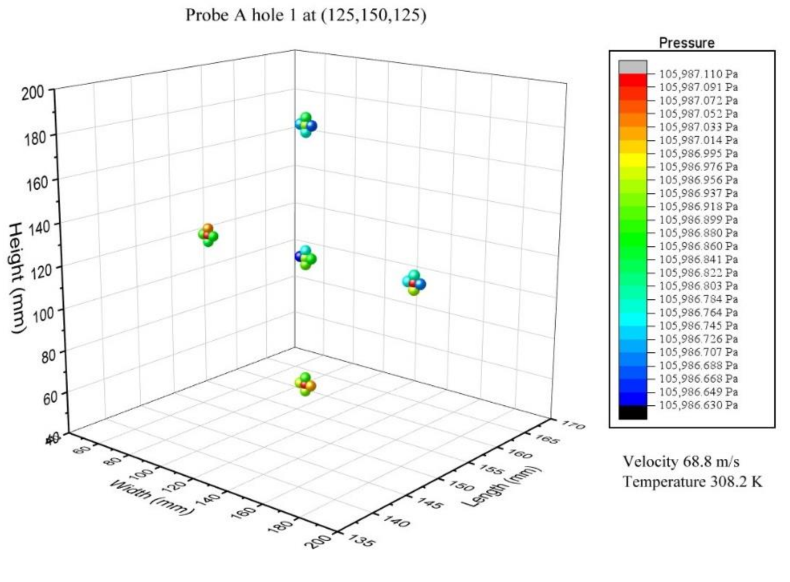


Figure 6

Grid Wise Representation of Pressure Values for Reference Point (125,150,125)



The three-probe flow analyser is also placed in the tunnel test section and the pressure values are charted out as in Table 3.

Table 3

Pressure values for Three-Probe Flow Analyser at Temperature 35.05^o C and Velocity 68.8m/s for Position 1

		Width(X)	**Length(Y)**	**Height(Z)**	**Pressure**
		mm	**mm**	**mm**	**Pa**
Probe A	Hole 1	100	150	100	102987.1
	Hole 2	96.8	150	100	102987.0
	Hole 3	103.2	150	100	102986.7
	Hole 4	100	150	103.2	102986.7
	Hole 5	100	150	96.8	102986.8
Probe B	Hole 6	160	150	100	102986.9
	Hole 7	156.8	150	100	102986.7
	Hole 8	163.2	150	100	102986.9
	Hole 9	160	150	103.2	102986.8
	Hole 10	160	150	96.8	102986.9
Probe C	Hole 11	40	150	100	102987.1
	Hole 12	36.8	150	100	102987.1
	Hole 13	43.2	150	100	102986.7
	Hole 14	40	150	103.2	102986.9
	Hole 15	40	150	96.8	102986.9

In order to validate the efficiency of pressure values obtained using both the instruments, a calibrated standard Pitot-Static probe is mounted at various positions in the tunnel at same velocity and pressure readings were charted out as in Table 4.

Table 4
Experimental Values Obtained at Temperature 35.05^o C and Velocity 68.8m/s *Using Pitot-Static Probe*

Point	Co-ordinate taken in the tunnel with centre (0,0,0)	Stagnation pressure	Static Pressure
	mm	Pa	Pa
1	(0,0,0)	105884.9	105883
2	(50,0,0)	105884.6	105883.9
3	(50,50,0)	105884.5	105883.3
4	(50,100,0)	105883.2	105883
5	(50,150,0)	105884	105883.6
6	(100,0,0)	105883.8	105883.8
7	(-100,-100,0)	105883.7	105883
8	(-100,-150,0)	105883.9	105883.5
9	(-150,0,0)	105884.3	105883.8
10	(-150,-50,0)	105883.4	105883.4

From the comparison made with the theoretical pressure values and pitot static probe values, the pressure values obtained with five probe flow analyser prove to more accurate. Moreover, as the number of holes in the pressure measuring instrument increases, the more compact way of calibrating the tunnel can be achieved.

Conclusion

From the results obtained theoretically and experimentally, it is well proved that the designed instruments are capable of using in varying Mach Number regimes. But in particular, the five-probe flow analyser prove to produce accurate results on comparison with standard Pitot measurements. The experimental results depict that the instruments are showing consistent result at various location in the wind tunnel test section. Also, it can be concluded that both the instruments are well suited for calibrating subsonic wind tunnel. The results so obtained can be used for conducting experimentation with the wind tunnels and will find most useful for future researches.

Abbreviations

C_N – Force Coefficient
F – Forces such as lift, drag etc
S – Area
V – Velocity

References

Lien, S. J., & Ahmed, N. A. (2011). An examination of suitability of multi-hole pressure probe technique for skin friction measurement in turbulent flow. *Journal of Flow Measurement and Instrumentation, 22*. Retrieved from 10.1016/j.flowmeasinst.2011.01.004

Main, J., Day, C. R. B., Lock, G. D., & Oldfield, M. L. G. (2016). Calibration of a four-hole pyramid probe and area traverse measurements in a short-duration transonic turbine cascade tunnel. *International Journal of Innovative Research in Science, Engineering and Technology, 1*. Retrieved from 10.1007/BF00190681

Muruga lal Jeyan, J. V., Kumar, M. S., & Rupesh, A. (2014). Aerodynamic design, fabrication and analysis of conical probe. *International Journal of Scientific and Engineering Research* (Paper Number: I043564), *5*(3). ISSN 2229-5518.

Rupesh, A., & Muruga lal Jeyan, J. V. (2020). Experimental and computational evaluation of five hole five probe flow analyzer for subsonic wind calibration. *International Journal of Aviation, Aeronautics, and Aerospace*, *7*(4), 1-42. https://commons.erau.edu/ijaaa/vol7/iss4/3

Yasar, M., & Melda, O. C. (2011). A multi-tube pressure probe calibration method for measurements of mean flow parameters in swirling flows. *Journal of Flow Measurement and Instrumentation, 9*. Retrieved from 10.15680/IJIRSET.2016.0504040