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

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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
\[ F = \frac{1}{2} \rho V^2 SC_N \]  

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 \(0-\beta-M\) 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° 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)*

![](image)

**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).
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 $\Psi$ 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°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 35.05° C*

<table>
<thead>
<tr>
<th>Mach No</th>
<th>Velocity (m/s)</th>
<th>Dynamic Pressure (Pa)</th>
<th>Stagnation Temperature (K)</th>
<th>Stagnation Pressure (Pa)</th>
<th>Static Pressure (Pa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>68.8</td>
<td>2899.232</td>
<td>311.0525927</td>
<td>109358.3153</td>
<td>106459.08</td>
</tr>
</tbody>
</table>

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 35.05° C and Velocity 68.8m/s for Position 1*

<table>
<thead>
<tr>
<th>Width(X)</th>
<th>Length(Y)</th>
<th>Height(Z)</th>
<th>Pressure (Pa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm</td>
<td>mm</td>
<td>mm</td>
<td></td>
</tr>
</tbody>
</table>

**Probe A**

- Hole 1: 100 mm, 150 mm, 100 mm, 105987.05 Pa
- Hole 2: 96.8 mm, 150 mm, 100 mm, 105986.91 Pa
- Hole 3: 103.2 mm, 150 mm, 100 mm, 105986.65 Pa
- Hole 4: 100 mm, 150 mm, 103.2 mm, 105986.65 Pa
- Hole 5: 100 mm, 150 mm, 96.8 mm, 105986.77 Pa

**Probe B**

- Hole 6: 160 mm, 150 mm, 100 mm, 105987.01 Pa
- Hole 7: 156.8 mm, 150 mm, 100 mm, 105986.68 Pa
- Hole 8: 163.2 mm, 150 mm, 100 mm, 105986.83 Pa
- Hole 9: 160 mm, 150 mm, 103.2 mm, 105986.94 Pa
- Hole 10: 160 mm, 150 mm, 96.8 mm, 105986.60 Pa

**Probe C**

- Hole 11: 40 mm, 150 mm, 100 mm, 105987.04 Pa
- Hole 12: 36.8 mm, 150 mm, 100 mm, 105986.78 Pa
- Hole 13: 43.2 mm, 150 mm, 100 mm, 105986.84 Pa
- Hole 14: 40 mm, 150 mm, 103.2 mm, 105986.63 Pa
- Hole 15: 40 mm, 150 mm, 96.8 mm, 105986.85 Pa

**Probe D**

- Hole 16: 100 mm, 150 mm, 40 mm, 105986.94 Pa
- Hole 17: 96.8 mm, 150 mm, 40 mm, 105986.80 Pa
- Hole 18: 103.2 mm, 150 mm, 40 mm, 105986.73 Pa
- Hole 19: 100 mm, 150 mm, 43.2 mm, 105986.87 Pa
- Hole 20: 100 mm, 150 mm, 36.8 mm, 105986.79 Pa

**Probe E**

- Hole 21: 100 mm, 150 mm, 160 mm, 105987.03 Pa
- Hole 22: 96.8 mm, 150 mm, 160 mm, 105986.92 Pa
- Hole 23: 103.2 mm, 150 mm, 160 mm, 105986.67 Pa
- Hole 24: 100 mm, 150 mm, 163.2 mm, 105986.86 Pa
- Hole 25: 100 mm, 150 mm, 156.8 mm, 105986.69 Pa
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)*

![Grid Wise Representation of Pressure Values for Reference Point](image)
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)
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°C and Velocity 68.8m/s for Position 1

<table>
<thead>
<tr>
<th></th>
<th>Width(X)</th>
<th>Length(Y)</th>
<th>Height(Z)</th>
<th>Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probe A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hole 1</td>
<td>100</td>
<td>150</td>
<td>100</td>
<td>102987.1</td>
</tr>
<tr>
<td>Hole 2</td>
<td>96.8</td>
<td>150</td>
<td>100</td>
<td>102987.0</td>
</tr>
<tr>
<td>Hole 3</td>
<td>103.2</td>
<td>150</td>
<td>100</td>
<td>102986.7</td>
</tr>
<tr>
<td>Hole 4</td>
<td>100</td>
<td>150</td>
<td>103.2</td>
<td>102986.7</td>
</tr>
<tr>
<td>Hole 5</td>
<td>100</td>
<td>150</td>
<td>96.8</td>
<td>102986.8</td>
</tr>
<tr>
<td>Probe B</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hole 6</td>
<td>160</td>
<td>150</td>
<td>100</td>
<td>102986.9</td>
</tr>
<tr>
<td>Hole 7</td>
<td>156.8</td>
<td>150</td>
<td>100</td>
<td>102986.7</td>
</tr>
<tr>
<td>Hole 8</td>
<td>163.2</td>
<td>150</td>
<td>100</td>
<td>102986.9</td>
</tr>
<tr>
<td>Hole 9</td>
<td>160</td>
<td>150</td>
<td>103.2</td>
<td>102986.8</td>
</tr>
<tr>
<td>Hole 10</td>
<td>160</td>
<td>150</td>
<td>96.8</td>
<td>102986.9</td>
</tr>
<tr>
<td>Probe C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hole 11</td>
<td>40</td>
<td>150</td>
<td>100</td>
<td>102987.1</td>
</tr>
<tr>
<td>Hole 12</td>
<td>36.8</td>
<td>150</td>
<td>100</td>
<td>102987.1</td>
</tr>
<tr>
<td>Hole 13</td>
<td>43.2</td>
<td>150</td>
<td>100</td>
<td>102986.7</td>
</tr>
<tr>
<td>Hole 14</td>
<td>40</td>
<td>150</td>
<td>103.2</td>
<td>102986.9</td>
</tr>
<tr>
<td>Hole 15</td>
<td>40</td>
<td>150</td>
<td>96.8</td>
<td>102986.9</td>
</tr>
</tbody>
</table>
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°C and Velocity 68.8m/s Using Pitot-Static Probe

<table>
<thead>
<tr>
<th>Co-ordinate taken in the tunnel with centre</th>
<th>Stagnation pressure Pa</th>
<th>Static Pressure Pa</th>
</tr>
</thead>
<tbody>
<tr>
<td>(0,0,0)</td>
<td>105884.9</td>
<td>105883</td>
</tr>
<tr>
<td>(50,0,0)</td>
<td>105884.6</td>
<td>105883.9</td>
</tr>
<tr>
<td>(50,50,0)</td>
<td>105884.5</td>
<td>105883.3</td>
</tr>
<tr>
<td>(50,100,0)</td>
<td>105883.2</td>
<td>105883</td>
</tr>
<tr>
<td>(50,150,0)</td>
<td>105884</td>
<td>105883.6</td>
</tr>
<tr>
<td>(100,0,0)</td>
<td>105883.8</td>
<td>105883.8</td>
</tr>
<tr>
<td>(-100,-100,0)</td>
<td>105883.7</td>
<td>105883</td>
</tr>
<tr>
<td>(-100,-150,0)</td>
<td>105883.9</td>
<td>105883.5</td>
</tr>
<tr>
<td>(-150,0,0)</td>
<td>105884.3</td>
<td>105883.8</td>
</tr>
<tr>
<td>(-150,-50,0)</td>
<td>105883.4</td>
<td>105883.4</td>
</tr>
</tbody>
</table>

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