Design and analysis of five probe flow analyser for subsonic and supersonic wind tunnel calibration

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Abstract. The flow angularity in a wind tunnel plays a major role in test section when testing models. The models are being tested at a mixture of flow velocity. Usually a subsonic wind tunnel is calibrated using a normal Pitot tube and supersonic wind tunnels with high efficiency probes. The calibration of a wind tunnel includes determining the Mach number range ad pressure range throughout the test section of the flow throughout the pattern of operating velocity. In the analysis it is noted that the sensitivities of the calibrating instruments are maximum when it is either cone or wedge shaped. When the wedge or cone angles are maximum, more accurate results are also obtained, but it’s not possible to have a maximum angle cone or wedge because of the detached wave and tunnel blockage factors. Hence in order to overcome these difficulties in measurement, a five probe flow analyzer has been designed. The five probe flow analyzer is used to determine the wind tunnel test section parameters like flow angularity, Pitot pressures, static pressures, wave angles, and the presence of test section noise. Over to these parameter, the stagnation states can also be determined using this analyzer. The proposed model is designed by getting optimum solutions from previous analysis and the existing data by considering all the aerodynamic and mechanical loading. This instrument designed is to be tested experimentally after carrying two and three dimensional computational analysis for Mach number ranging from 0.5 of 3. Also it is designed to fit successfully for 0.3m and 0.6m test section wind tunnel to obtain reasonably merging solution with theoretical and experimental results.

1. Introduction
The change in kinetic pressure are accompanied by equal and opposite changes in static pressure. The static pressure defined for present purposes as the pressure sensed by a measuring device at rest relative to the fluid (i.e. moving with the fluid).[1] The total pressure defined as the pressure obtained when the fluid is brought to rest relative to the probe. It follows that the kinetic pressure can be determined directly by measuring high pressure. If velocity is required, then there is a need to determine the density as well. This is usually done by measuring the (absolute) pressure and temperature at some point in the flow field, and invoking the perfect gas equation: in practice the pressure changes arising from the motion in incompressible flow are negligible in comparison with the absolute pressures.[2][3]

2. Design of conical probes
Conical probes have been used determination of the Mach number flow direction and total pressure at supersonic and subsonic speeds. It is mainly because their shape will be offering less interference to flow the hemispherical types. The smaller the apex angle of the cone of the wider the range of Mach over which a smooth pressure response to obtained. At the same time, sensitivity of the side holes to change in the flow direction increases with angle of the cone, so that some compromise is necessary. [4] A cone angle of 60 degrees is found to be suitable for speeds above M = 1.5 although angle of 40 degrees have been used to give a slightly lower limit.

The multi-hole probe is devised by means of the AutoCAD with the specifications according to the needs and after taking into accounts various features such as tunnel blockage, model design and size and shock wave. It is planned in accordance with the conceptual evaluation and is endowed with the five-hole conical probe wedge type.

![Figure 1. Schematic diagram of 5 probe flow analyzer.](image)

The wedge type probe is endowed with the following dimensions: It is 140mm long and 60mm wide. The front facing edge of the wedge and tip of the multi-hole probe have a dimension of 30mm each. Each probe is effectively fitted with the probe adopter, multi-hole, and small adopter. The main adopter contains tube having $\phi$30 along with length 130mm. It is coupled to the particular wedge from the yaw meter. The dimensions of the wedge are 140mm length, 60mm wide and also the thickness involving 20mm. It have 4 holes in front of the wedge with regard to inserting the particular conical probe and diameter is usually $\phi$10mm. The actual conical probe contains the diameter involving $\phi$10mm and length is usually 30mm. The actual probe adopter can be used to insert in the particular multi hole probe from the wedge possesses the particular diameter from the $\phi$10mm along with 70mm length. The small adopter can be used to help conical pets from the probe together with along 30mm length and that is placed from the smaller adopter featuring a diameter involving $\phi$10mm along with 55mm length.[5]

3. Methodology
The material selection was done by comparing the mechanical properties of stainless steel, aluminum and copper. It is clear that stainless steel is largely used because the corrosion resistance of its alloys depends on the preservation of the stainless passivation layer needing the least Chromium concentration of 11 % and exposure to an oxygenated atmosphere. Low temperature hot water systems are devised to restrict oxygen ingress which adversely affects the preservation of the passive layer. As it is a non-reactive base metal, Copper is also trivially prone to the creation of corrosion and assault by chlorides leached from insulating foam. Nevertheless, while scaling up the storage capacity is shored up, the yield strength of Copper makes it non-competitive economically vis-a-vis Stainless Steel substitutes. Copper and aluminum alloys are endowed with superior thermal conductivities and lesser electrical resistivity than stainless steel.[6] It is observed that the low thermal conductivity of stainless steel tends to enhance the scope of heating. The densities of the stainless steels are marginally greater than that of aluminum. Stainless steel emerges as the solitary alloy to possess higher properties at 200°C and above and hence is employed to originate the multi-hole probe. Computational fluid dynamic analysis and Nastran analysis were conducted for predicting the best material for manufacturing the multi-hole probe.[7]
3.1. CFD analysis: 2D analysis method
The following conditions are used to derive the real time conditions of the CFD computational analysis. The Mach number is varied with constant ambient temperature and ambient pressure. The output of the CFD is static pressure, static temperature, turbulence viscosity and velocity.

In MACH 1, the ambient pressure and ambient temperature is 1.01325 bar and 288K. figure (a), (b), (c) and (d) shows the static pressure, static temperature, turbulent viscosity and velocity magnitude of the probe.

Figure 2(a) shows the static pressure output of the probe. It shows the detached wave is formed by the shock wave. It is not fitted with the pressure. So the pressure is accumulated in front of the probe tip in Mach1.it is clearly shows in figure 2(a) by the yellow color.Figure 2(b) shows the static temperature which also same as for the static pressure which is shown by the yellow color on tip of the probe, the Velocity of the air blocked by the detached wave. So the velocity is reduced at the tip of the probe which is shown by green color in figure 2(d).

In MACH 2, the detached wave is reduced, when Mach number increases. Figure 3(a), 3(b), 3(c) and 3(d) shows the static pressure, velocity magnitude, static pressure and turbulence viscosity of the probe.

Figure 2. 2D Graphical output of the conical four-hole probe.
The Mach number increases, the shock wave coupled with the air pressure and create the shock wave angle with the probe. The figure 3(a) clearly shows the pressure fitted with probe tip and gives the angle of shock wave. The static pressure of probe with maximum value shows in red color. The static temperature varied in velocity varies which is shown by the blue color. Figure 3 (c) shows the variation of the static temperature with the minimum value which is shown figure 3 (c) as blue color. The turbulent viscosity shows in figure 3(d) with minimal range of variation shown by light green color.

From these almost all 2D graphical analysis shows, whether the Mach number increases, the own wind pressure clearly measured with the probe very accurately. Whenever the own air pressure increases the supersonic condition, the current velocity of an wind goes towards very high value which is to be also measured with the probe.

3.2. Nastron analysis

**Table 1. Experiment results for Aluminium.**

| Mach Velocit y | Pressure | Displacement (max) mm | Displacement (min) mm | stress(max) kpa | stress(min) kpa |
|---------------|----------|------------------------|------------------------|-----------------|-----------------|
|               | m/s      | Pa                     | X Y Z                  | min prin        | max prin        |
| 0.2           |          | 68.6                   | 3002.0                 |                 |                 |
| 0.8           |          | 343.1                  | 300204.9               |                 |                 |
| 1             |          | 686.2                  | 675461.0               |                 |                 |
| 2             |          | 1029.3                 | 300204.9               |                 |                 |
| 3             |          | 1852.5                 | 675461.0               |                 |                 |

Figure 3. MACH 2 output responses of the probe.
In this analysis, the tabular columns are shows that the experimental investigation of the aluminium, copper and stainless steel material probes and which material is to be used for fabricating the multihole probe. From this experiment results, the high hardness and strength material is measured and that material is used for fabricating the multihole probe [8][9] The inputs are pressure and velocity at different Mach number conditions and the outputs are displacement at minimum and displacement at maximum and stress at minimum and stress at maximum that used to select the material. The experimental results are shown in the below tables for different materials like aluminium, copper and stainless steel.

In table 1, the aluminum material probe is tested at the different mach number conditions and the outputs are displacement, stress and shear are measured. The displacement has three coordinates X, Y and Z with minimum and maximum. The stress at minimum and maximum are measured at different conditions of the Mach number by using the CFD analysis. Different mach numbers and pressures are given as input for probe and the outputs are displacement and stress with shear.

| Mach | Veloc | Pressu | Displacement (max) mm | Displacement (min) mm | stress(max) kpa | stress(min) kpa |
|------|-------|--------|-----------------------|-----------------------|----------------|----------------|
|      | m/s   | Pa     | X                     | Y                     | Z             | Z             |
|      |       |        |                       |                       |               |               |
| 0.2  | 3002  | 1.75E  | 1.70E                 | 2.05E                 | 2.04E         | 2.02E         |
|      |       |        | -02                   | -02                   | -02           | -02           |
| 0.8  | 48032 | 2.12E  | 2.06E                 | 2.48E                 | 2.46E         | 2.45E         |
|      |       |        | 2.46E                 | 2.59E                 | 5.35E         | 5.49E         |
| 1    | 75051 | 4.38E  | 4.26E                 | 5.13E                 | 5.09E         | 5.06E         |
|      |       |        | 5.06E                 | 5.36E                 | 5.36E         | 5.36E         |
| 2    | 30020 | 1.75E  | 1.70E                 | 2.05E                 | 2.04E         | 2.02E         |
|      |       |        | -00                   | -00                   | -00           | -00           |
| 3    | 67546 | 3.94E  | 3.83E                 | 4.61E                 | 4.58E         | 4.56E         |
|      |       |        | 4.56E                 | 4.82E                 | 9.95E         | 1.02E         |
| 3    | 1.0   | 4.9    | 4.9                   | 4.9                   | 4.42E         | 4.54E         |
|      |       |        | 4.42E                 | 5.35E                 | 3.38E         | 7.73E         |

In table 2, the copper material probe is used to analyze their strength and hardness at different Mach number conditions. The table 2 is shown that the copper material outputs at different Mach number and output are displacement and stress. From 0.2 to 3 Mach number conditions are checked and the velocity range is varied from 68 to 1030 m/s also the pressure is varied upto 68000Pa. The maximum displacement is occurred at maximum condition in Mach number 3.

In table 3, the stainless steel material is analyzed at different Mach number conditions from 0.2 to 3 and different velocity and pressure applied on the multihole probe. The experimental outputs of the probe are analyzed by using the Computational Fluid Dynamics (CFD). The shear is the component of stress coplanar with a material cross section. Shear stress arises from the force vector component parallel to the cross section.

The nastran analysis is conducted for different materials such as Aluminium, copper and stainless steel and its output are shown in the following tabular columns.

From the above all tabular columns of the materials, the stainless steel material has the best values in displacement and stress. From the figure, the displacement and stress both are depend on the material properties. Theoretically, the mach number 2.8 is given the best result and the performance of the material is also very good at this condition. So, from the all conditions are satisfied for stainless steel material probe and its results are also good for all mach number conditions. Form the above results, the stainless steel material is used for fabricating the probe.
Table 3. Experiment results for stainless steel.

| Mach | Veloc. | Pressure (minimum) | Displacement (minimum) | Displacement (minimum) | Stress(minimum) | Stress(maximum) |
|------|--------|---------------------|------------------------|------------------------|-----------------|-----------------|
|      | m/s    | Pa                  | X                      | Y                      | Z               | Prin            | Max             | Pri            | Shear          |
|      |        |                     |                        |                        |                 | Prin            | Max             | Pri            | Prin           |
| 0.2  | 68.6   | 3002.0              | 0.0                    | 0.0                    | 0.0             | 0.0             | 38590           | +06            | +06            | +04            | 45              |
| 0.8  | 5      | 8                   | 53                     | 469                    | 0               | 78              | 75              | 87             | 0              | +07            | +07            | 60              | 1.07E           | 37.9            |
| 1    | 1      | 2                   | 40                     | 296                    | 1               | 77              | 74              | 93             | 0              | +08            | +07            | 62              | 1.67E           | 58.6            |
| 2    | 2      | 4.9                 | 58                     | 182                    | 3               | 09              | 95              | 71             | 0              | +08            | +08            | 62              | 3.77E           | 6.66E           | 234             |
| 3    | 9.3    | 1.0                 | 57                     | 660                    | 6               | 96              | 64              | 34             | 0              | +09            | +08            | +08             | +07             | 62              | 1.50E           | 527             |

4. Summary and conclusions

The wedge type five hole conical probes flow analyzer is planned by their shock wave angle and designed according to indicated measurements. The planned wedge type probe (flow analyzer) setup is examined and effectively tried by employing the Computational Fluid Dynamics (CFD) investigation system. The composed wedge type probe is applied within the horizontal movement and measured the yaw axis angle moments. The distinctive sorts of materials, for example, aluminum, copper and stainless steel tests are applied to break down their execution in the continuous trials and their yields as far as displacement and stress are evaluated. Through this material execution analysis, the stainless steel material is found to yield the best come about contrasted with those of different materials.

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