Elementary characterization of smoke tunnel using flow over a circular cylinder

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Abstract. The utilization of the smoke tunnel for flow visualization of aerodynamics studies needs calibration of the tunnel. This paper aims to describe the characterization of the smoke tunnel using the smoke injection technique. The main phenomenon considered is the wake behaviour occurring at the downstream side of the cylinder. The experiment is conducted by injecting the smoke perpendicular to a circular cylinder placed in the tunnel. The visualized smoke flow lines resemble the streamline patterns which will reveal the wake behaviour. The procedure of smoke based visualization was carried out for various Reynolds numbers and the corresponding physics is described with the limitations of the tunnel.

1. Introduction
The Wind tunnel has been an attractive area for aerodynamics researchers for more than a century. A Smoke tunnel is a type of wind tunnel which is used prominently for visualization. The principle behind this tunnel is introducing smoke in the tunnel and subjecting the model in the flow to study about the flow behaviour. The characterization of the smoke tunnel is to provide significant data with appropriate validation. There are wide varieties of techniques for calibrating a wind tunnel in practice. The flow quality is tested with a simple circular cylinder setup because of its significance. The visualization of the flow behaviour is achieved through the application of the laser light sheet technique.

From the previous works, for example, the work in the research wind tunnel of Marcelo and his fellows delivered a brief idea about the calibration and design of a wind tunnel [1]. A detailed Calibration of a subsonic wind tunnel for 2D is given by Robert and Jonah [2]. The wind tunnel calibration techniques by Pope explain calibration about various wind tunnel models and their parameters [3]. The observation of Robert and Stephen at low speed in draft wind tunnels provided the characteristics and measurements [4]. An interpretation by Boyle on low-speed wind tunnel testing focuses on analysing wind tunnel performance and parameters [5].

The explanation made by Bradshaw and Pankhurst on the design of wind tunnels which provides information regarding wind tunnels working [6]. Mueller presented the apparatus and techniques for smoke visualization of both subsonic and supersonic flows play an important role in selecting the technique suitable for specific applications [7]. There are multiple modes of smoke injection and the mode information can be extracted based on visualization patterns. Information on the jet mode is given by Kannan B T [8] & [9]. The papers by Karthikeyan et.al gives a detailed explanation of wake mode behaviour [10] & [11]. The current work deals with calibrating the smoke tunnel and analyse its performance parameters.
The objectives of the present characterization are 1. Optimizing the velocity for the smoke tunnel concerning the rpm of the motor, 2. Analysing the down steam flow of the smoke in the test section, 3. Observing the changes due to a circular cylinder is placed in the downstream of the flow. The ultimate motive behind this calibration is to find the working flow regime for extracting valid data for any form of smoke tunnel experiments and its related studies.

2. Experiment methodology

The experimental setup is situated in the Aerospace hanger of SRM Institute of Science and Technology. The tunnel under elementary characterization is a simple smoke tunnel configuration for determining the flow field physics via visualization.

2.1. Smoke tunnel setup

The inlet of the smoke tunnel allows the atmospheric air to enter due to the pressure created by the fan placed in the downstream. The settling chamber consists of honeycomb cells with an aspect ratio of 10.416 and few screens of flow straighteners to minimize the turbulence and fluctuations in the flow. The distance between the inlet and test section should be minimum. The smoke is injected in the contraction area from a collecting duct through an injector which points normally to the flow direction. The contraction area is of ratio 6.33:1 by scaling down and the length should be small to have a larger contraction ratio. The purpose of this section is to accelerate the incoming flow and decreasing the cross-section velocity.

The test section is 13.1 cm × 21.4 cm in width wise and 34.6 cm × 21.4 cm in lengthwise, the rectangular shape is utilized to justify the purpose of the application. The test section is designed particularly to reduce boundary layer growth and static pressure. The diffuser area ratio is scaled up by 1:1.21 and its function is opposite to the contraction area. The diffuser area ratio is selected in accordance to avoid downstream air reversal and boundary layer separation. The three-phase AC induction motor unit drivers air with rpm of 1411 into the tunnel and the fan with appropriate speed ratio give the required pressure rise in the small blade area. The speed of the motor is controlled by the ABB ACS 380 model of variable frequency drive.

![Figure 1. Smoke Tunnel Setup.](image-url)
2.2. Vane Anemometer Setup
The velocity variation of the test section is tested for determining the low turbulent area. This is achieved by the application of a vane anemometer placing normally to the flow direction. The vane anemometer used for this experiment is from the laboratory and can measure velocity up to 30 m/s. The vane anemometer is initially checked for its sensitivity towards the airflow. Then velocity variation is measured by varying the motor RPM at an increasing range with an equal interval.

2.3. Flow Visualization Setup
The visualization technique used is a laser light sheet that illuminates a light in one direction and uses a cylindrical lens. The light intensity detected in the plane of an observing camera depends on flow geometry and particle size. The laser sheet is implemented in this study due to its fineness of the beam and monochromatic nature. The smoke is made to move in the upstream airflow and the illuminated light is made to fall perpendicular to the flow. The speed of the flow should be low enough to observe the flow field to observe the streak lines. Note that the smoke used in the present study is generated by an incense material.

3. Results and Discussion
The elementary characteristics of a wind tunnel are performed around a circular cylinder and the calibrated parameters are reported as following.

3.1. Velocity Calibration
The velocity calibration is performed by a vane anemometer which is placed perpendicular to the flow in the test section. The readings are collected by varying the rpm of the motor using the microcontroller. This part of the experiment will be a preliminary analysis of the wind tunnel to test the flow speed. The data obtained is compared with the old calibration data to authorize the results. The graphs are plotted to check the linearity, by making rpm as the axis of abscissa and velocity as the ordinate. The linear variation stands as proof for the direct relation between the rpm of the motor and the flow velocity. The suitable flow velocity is from 2.5 to 4 m/s which corresponds to rpm between 400 and 600. This flow velocity range can be adopted for the initial setting for performing the experiments in the smoke tunnel. According to this calibration, the obtained flow velocity gives an undisturbed flow especially the advantage of coherent visualization of smoke streak lines.

| RPM  | Velocity (m/s) |
|------|----------------|
| 700  | 4.8            |
| 650  | 4.45           |
| 600  | 4.1            |
| 550  | 3.75           |
| 500  | 3.45           |
| 450  | 3.1            |
| 400  | 2.8            |
| 350  | 2.4            |
Table 2. New data collected from the smoke tunnel, where RPM is the rotational speed of the drive motor and velocity denotes the flow speed in the test section.

| RPM | Velocity (m/s) |
|-----|----------------|
| 700 | 4.6            |
| 600 | 3.9            |
| 500 | 3.3            |
| 400 | 2.6            |
| 300 | 1.9            |
| 200 | 1.1            |

Figure 2. The RPM – velocity relationship (old calibration)
3.2. Flow Behavior in Test Section
The smoke injected in the contraction area is made to flow through the test section to visualize the streak line pattern. This process of subjecting the smoke simply through the test section gives information about the wake structure at different velocities (refer to Figure 4 - 6). The velocity < 2.5 m/s gives nonparallel streak lines with the wakes. The range from 2.5 to 4 m/s shows parallel and perfect streak lines. The flow velocity > 4 m/s creates parallel streak lines with jet influence is observed. The smoke takes up the pattern of streak lines which is helpful for visualization between 400 to 600 rpm set in frequency drive. Due to the gradual increase in rpm, the laminar streak lines get disturbed and at maximum rpm, it attains turbulent streak lines. The streak line patterns at various rpm are tested and the variations are analysed. The streak lines pattern primarily depends on the smoke injection and flow velocity.

Figure 3. The RPM – velocity relationship (new calibration).

Figure 4. Non Parallel Streak lines (with wake flow).
3.3. Flow Over a Circular Cylinder

The smoke injected in such a way to flow over a circular cylinder and to find the vortex shedding pattern at different velocities (refer to figures 7 - 9). The circular cylinder is of diameter 34.95 mm with a holder by which it is placed inside the test section. The velocity range < 2.5 m/s no separation, vortex shedding with recirculation zone. As the range lies between 2.5 to 4 m/s the vortex shedding with extended recirculation zone. Then the velocity goes higher than 4 m/s to form alternative vortex shedding. This represents the flow patterns over the bluff body and the proper positioning of the model concerning the flow velocity. Note that the recirculation zone is seen as qualitative over quantitative result.
4. Conclusion
Flow visualization by laser sheet technique adds an advantage to focus on the structures of wakes and vortex shedding at different velocities. The calibration data collected from the experimental study shows the following results, as the rpm of the motor increases, there is an increase in the flow
velocity which represents a linear variation. The smoke tunnels working regime range is from 2.5 to 4 m/s, this is concluded by adopting two different flow analysis. In the first case, where there is simple smoke flow through the test section under the working regime range (2.5 to 4 m/s) gives flow free from the influence of wakes and jets which gives perfect streakiness for visualization. Whereas in the other case, in which smoke flow is subjected over a circular cylinder between the working flow regime the extended recirculation zone. As the investigation suggests the working flow regime gives genuine results while performing the experiments. The characterization determines the correct setting of the motor rpm to give respective velocity, streak lines, and vortex shedding.

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5. References
[1] Assato M, Girardi R, Fico N, Mello O and Komatsu P 2004 Research Wind Tunnel of the Aeronautical Institute of Technology: Conceptual Design and Calibration. In 42nd AIAA Aerospace Sciences Meeting and Exhibit (p. 724).
[2] Englar, Robert J., and Jonah Ottensoser 1972 Calibration of Some Subsonic Wind Tunnel Inserts for Two-Dimensional Airfoil Experiments. No. TN-AL-275. David W Taylor Naval Ship Research and Development Centre Bethesda Md Aviation and Surface Effects Dept.
[3] Pope, Alan. Wind-tunnel calibration techniques. No. AGARDGRAPH-54. Advisory Group for Aeronautical Research and Development PARIS (FRANCE), 1961.
[4] Batill S M, Nelson R C 1989 Low speed, indraft wind tunnels. In Frontiers in Experimental Fluid Mechanics (pp. 25-94). Springer, Berlin, Heidelberg.
[5] Barlow JB, Rae Jr WH, Pope A 2015 Low speed wind tunnel testing. INCAS Bulletin. 7 133.
[6] Bradshaw P, Pankhurst R C 1964 The design of low-speed wind tunnels. Progress in Aerospace Sciences. 5 1-69.
[7] Mueller T. 1980 On the historical development of apparatus and techniques for smoke visualization of subsonic and supersonic flows. In 11th Aerodynamic Testing Conference 420.
[8] Kannan B T 2015 Computation of an axisymmetric jet using OpenFOAM. Procedia Engineering. 127 1292-9.
[9] Kannan BT, Seshan P, Senthilkumar S 2016 Large Eddy Simulation of isothermal cruciform jet flow: Preliminary results Perspectives in Science 8 10-2.
[10] Karthikeyan, S, Kannan B T and Senthilkumar S 2018 Active Vortex Shedding Control for Flow Over a Circular Cylinder Using Rearward Jet Injection at Low Reynolds Number. In Innovative Design, Analysis and Development Practices in Aerospace and Automotive Engineering (I-DAD 2018) (pp. 135-141). Springer, Singapore.
[11] Karthikeyan S, Senthilkumar S, Kannan B T and Chandrasekhar U 2019 Numerical Analysis on Effect of Jet Injection on Vortex Shedding for Flow Over a Circular Cylinder Arabian Journal for Science and Engineering 44 1475-88.