DEVELOPMENT OF AN ECONOMISED FLOW VISUALIZATION FACILITY (SMOKE TUNNEL) FOR THE VISUALIZATION OF EXTERNAL FLOWS PAST BODIES

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***ABSTRACT*:**

The insight into a physical process is always improved if a pattern produced by or related to this process can be observed by visual inspection. Flow visualization is one of the many available tools in experimental fluid mechanics which renders certain properties of a flow field directly accessible to visual perception which are otherwise invisible to the human eye.

The general principle of flow visualization is to render the "fluid elements" visible by observing the motion of suitable selected foreign materials added to the flowing fluid. The foreign material added to the flowing fluid in this case is smoke, generated from the kerosene in the smoke generator.

This paper describes the development of such a flow visualization facility (Smoke tunnel) in the fluid mechanics laboratory of National Institute of Technology, Srinagar, India at a very economic cost primarily aimed at providing teaching aid in the study of external flows in fluid mechanics. In the real world it can be used to study problems like boundary layers, air pollution,

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design of exhaust system of locomotives, cars, ships, topographical influence of disposal of stack gases etc.

Keywords: smoke tunnel, flow Visualization, fluid, external flows, flow pattern.

1. INTRODUCTION

Flow visualization is one of the many available tools in experimental fluid mechanics. It differs from other experimental methods in that it renders certain properties of a flow field directly accessible to visual perception. The insight into a physical process is always improved if a pattern produced by or related to this process can be observed by visual inspection. This becomes obvious if we think of a fluid mechanical process where a fluid is flowing in a channel or around a solid obstacle. By observing such a flow pattern, which might be stationary or variable with time, we can get an idea of the whole development of the flow.

However, most fluids, gaseous or liquid, are transparent media, and their motion remains invisible to human eye during a direct observation. In order to be able to recognize the motion of the fluid, one must therefore provide a certain technique by which the flow is made visible. Such methods are called flow visualization techniques, and they have always played a role in understanding fluid mechanical properties. However, besides such instructive applications, the greater importance of many flow visualization techniques is that one can derive quantitative data from the obtained flow picture. Such techniques provide information about the complete flow field under study without physically interfering with the fluid flow. In contrast, a single flow measuring instrument, such a certain temperature or pressure probe, provides data for only one point in the flow field, and in addition, the flow is disturbed to a certain degree owing to the physical presence of the measuring probe.

The methods of flow visualization can be classified roughly into three groups:-

1) The first class comprises all techniques by which a foreign material is added to the flowing fluid that might be gaseous or liquid. The foreign material must be visible, and if the particles of which the material is composed are small enough, one may assume that the motion of these particles is the same as that of the fluid, in direction and magnitude of velocity. The visualization is thus an indirect method, since one observes the motion of foreign material instead of the fluid itself. The difference between the movement of the fluid and that of the foreign particles can be

minimized, but not totally avoided, by giving to the particles a density almost coinciding with that of the fluid.

2) The variation of the fluid density is at the same time the key to the second class of visualization methods. Since the fluid density is the function of the refractive index of the flowing medium, compressible flows can be made visible by means of certain optical methods that are sensitive to changes of the index of refraction in the field under investigation. The flow field with varying density is, in optical terms, a phase object: that is, a light beam transmitted through this object if affected with respect to its optical phase, but the intensity or amplitude of the light remains unchanged after the passage of the object. An optical device behind the object provides in a recording plane a non-uniform illumination, according to the phase changes caused by the object. From the pattern in the recording plane one can make conclusions concerning the density variations in the flow field.

3) The third group of visualization techniques is somehow a combination of the two above mentioned principles. In this case, the foreign substance introduced into the flowing fluid is energy (e.g. in the form of heat or electric discharge). The fluid elements thus marked by their increased energy level sometimes need an optical visualization method so that they can be distinguished from the rest of the fluid. In other cases the energy release is so high that the marked fluid methods become self-luminous and can be directly observed. These methods are often applied to flow with a low average density level. Density changes occurring in such flows can be too weak to be detected by an optical method. Hence, this third group of visualization technique is at least partly applied to a third class of flows, which one often distinguishes from the ordinary incompressible and compressible flows, namely, the class of rarefied or low density gas flows.

Flow visualization using a Smoke tunnel lies in the first category. Smoke streaks can be introduced into the flow to indicate not only its direction, but also whether it is smooth or disturbed. By studying the flow of the smoke particles, one can get an idea of the actual flow field.

The idea of introducing smoke into an airstream for the purpose of visualization is, of course, old and had already been applied to scientific experiments by Ludwig Mach. An essential portion of the progress and refinement of the smoke technique is due to the work of Brown at the university of Notre Dame who systematically developed the generation of an appropriate smoke as well as the performance of suitable wind tunnels, later referred to as “smoke tunnels”.

An important aspect of this project which needs to be highlighted here is that the Smoke tunnel has been fabricated at a cost which is very economical, as compared to the other flow visualization facilities which are available these days.

For good results, the smoke chosen for flow visualization should have the following qualities:-

- The smoke should be white, dense, non-poisonous and noncorrosive.
- Smoke should have nearly the same density as that of the surrounding air; hence the smoke filaments are not appreciable influenced by gravity.
- Smoke particles should not disturb the flow in the smoke tunnel by formation of deposits on the surface of the models or block the tubes used for smoke injection.
- Production of smoke should be easily and readily controllable.

1.1 LITERATURE REVIEW

Stephen M.Batill used the smoke wire technique for visualization of transition of the free shear layer associated with laminar separation bubble of NACA 663-018 airfoil section at low Reynolds number. In this technique fine smoke streaklines were introduced into the flow field by using an oil coated fine wire[1]

C.H.Sieverding used coloured smoke visualization technique for study of secondary flows in straight turbine cascades[2] New techniques like computer visualization of simultaneous three-dimensional vector and scalar fields such as velocity and temperature in reacting fluid flow fields i.e. the virtual smoke technique is complicated and expensive technique[3].

But all these techniques have various problems associated with them like complex nature of the techniques used, big budgets and as such financial problems, professional experts required, to mention a few.

1.2 CLASSICAL SMOKE TUNNELS

Smoke tunnel is basically an open circuit, low speed wind tunnel. The flow through the tunnel is induced by the suction of atmospheric air through the test section, using a simple axial fan. The simple design of smoke tunnel is shown in figure 1.

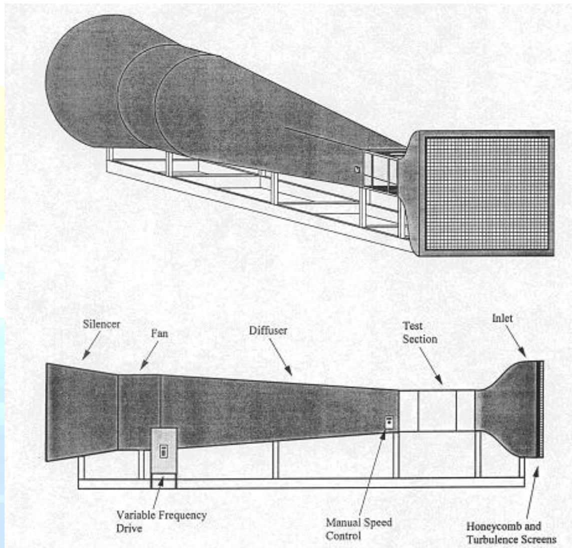

Figure 1: Simple Smoke Tunnel

The major components of the tunnel are:

- Screened section
- The double contraction
- Neck region
- Smoke rake (In test section)
- Test section
- Diffuser
- Axial fan and motor assembly

2 PROPOSED ECONOMIC DESIGN

The expensive setup of smoke tunnel is replaced by using a better economic design without compromising on the visibility of flow visualization results. Smoke generator and smoke circuit parts have been discussed separately.

Schematic diagram of proposed smoke tunnel is shown below:

Fig 2.0: New Economic proposed Design

2.1 DETAILS OF INDIVIDUAL COMPONENTS

A) Screened Section:

The screened section is a honey comb structure and represents front part of the tunnel. It is the means for receiving the atmospheric air and breaks down big lumps of air into fine streaks. It is fabricated in four parts, bolted tightly with each other and separated from each other by thin wire mesh or graded screens for reducing air turbulence. Screened section is the part where atmospheric air makes its first entry into the tunnel.

B) Double Contraction:

This portion of the tunnel exactly following the screened section is double contraction. The double contraction contracts in both horizontal and longitudinal direction and thus contacts the streaks of air horizontally as well as longitudinally. The function of the double contraction is to merge the air streaks into a small area of cross section.

C) Neck Region:

This is connecting section between the double contraction and the test section. It is a connection that passes fine atmospheric air streaks into the test section and also contains smoke rake.

D) Smoke Rake:

It is an essential part of the tunnel and can be considered as the last portion of the smoke generator circuit. It is located in the rare portion of the neck region and contains 28 small pipes about 2mm in diameter attached on a 3cm diameter conduit pipe. Smoke rake is the component that introduces fine smoke streaks in the tunnel and is an important part that dictates the proper visualization.

E) Test Section:

This is the core component of the tunnel where the visualization takes place. It is rectangular in cross section 30×6.5 and is about 80 cm in length. The model for flow visualization is placed in this section and the flow pattern is observed through the transparent window placed in the front portion of this section. The top portion of the tunnel is provided with fluorescent lamp for better flow visualization. Within the Test section is a Clamping mechanism on which the various models can be clamped to perform the visualization tests.

F) Diffuser:

It is directly attached with the test section for the removal of the smoke from the test section.

G) Axial Fan and Motor Assembly:

An axial fan of 1 h.p is attached with the diffuser in the last portion of the tunnel. The Fan provides the required suction for the fine smoke streaks coming out of the smoke rake. The fan is rotated at low rpm to prevent the high suction of the smoke that reduces its visibility and renders visualization as ineffective.

2.2 SMOKE GENERATOR AND SMOKE CIRCUIT:

The smoke that is used in the setup is generated in a kerosene smoke generator. In order to increase the density (visibility) of the smoke, it is first compressed in a collecting tank (Smoke tank) before passing it through the smoke rake .The smoke is taken from the Smoke generator to the Storage tank by means of an exhaust fan kept in a housing. As an exhaust fan works on the basis of a pressure difference across it, the smoke circuit needs to be kept open initially to avoid the initial air lock. Once the density of the smoke is sufficiently increased (which becomes apparent once the smoke becomes white), the opening is closed and the smoke is allowed to pass through the smoke rake.

Fig 2.2: Smoke generator and smoke circuit

3 BASIC WORKING PROCEDURE

The axial fan is turned on and air is sucked in through the screened section which breaks down big lumps of air. The use of the screened section is important because in case the enters the Test section in the form of lumps, it will certainly disturb the flow of streamlines and the visualization will not be clear. The air is further compressed as it passes through the contraction cone.

The smoke from the smoke generator enters the smoke rake and exits through the needles provided in the smoke rake in the form of fine streaks. The smoke streaks as such cannot travel on their own, as such there has to be a suction force (which is provided by the motor and fan assembly). As the suction speed goes on increasing , the density of the smoke streaks goes on decreasing , so it is important to operate the tunnel only upto those speeds upto which the smoke streaks are clearly visible . In case one is interested in further increasing the speed to visualize high Reynold number flows, then the size of the needles in the smoke rake has to be increased.

The smoke streaks coming out of the needles of high diameter would retain their visibility even at high speeds and consequently high speed flows can be visualized with ease

These smoke streaks then pass through the test section where the objects are clamped over which the flow field is to be observed. By analyzing the motion of the smoke particles we can get an idea of the actual flow profile.

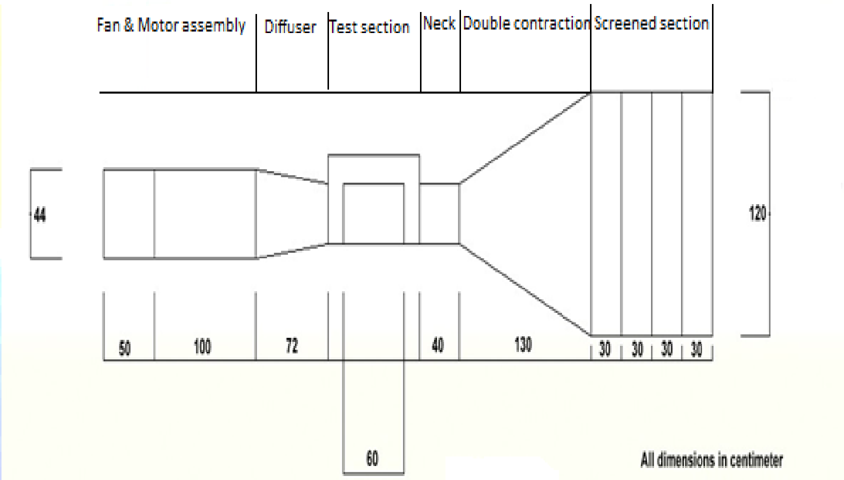

Fig 3(a): Smoke tunnel (Front View)

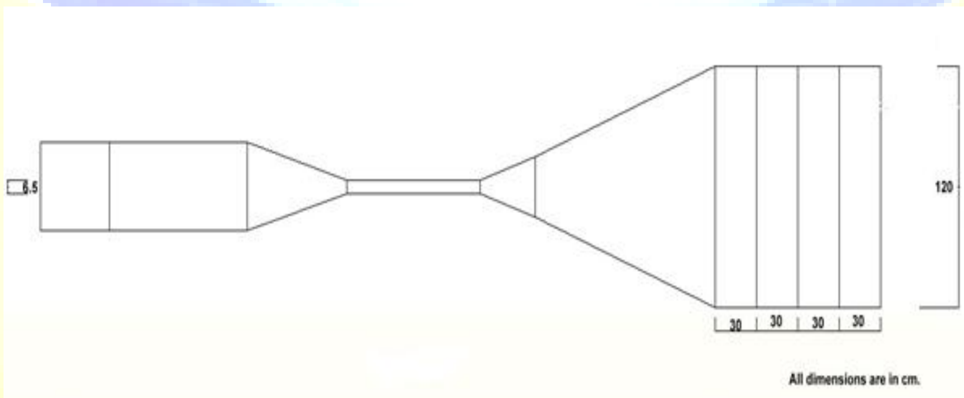

Fig 3(b): Smoke tunnel (Top View)

4 ECONOMIC DESIGN OF INDIVIDUAL COMPONENTS

The proposed design proved to be economical in the sense that every single component of smoke tunnel was fabricated by keeping in mind the general average cost of projects in colleges like NITs and IITs in India.

Major cutbacks in cost have been achieved by incorporating a couple of innovative ideas in the design of the Smoke rake:

1) The conventional smoke rake (which consists of a simple pipe with holes in it) has been replaced by an arrangement which consists of a simple conduit pipe 3 cm in dia in which 28 pipes each 2mm in dia have been fitted. The advantage of using these 2 mm pipes is that now the smoke leaves the smoke rake in the form of fine streaks as against a diffused flow in conventional smoke rakes, thus reducing the need of a fine control in air suction
2) The smoke rake has been given an aerofoilic shape as against a simple pipe. As a result when the suction air passes over the smoke rake, by the time it reaches the exit point of the smoke, the flow has got rejoined after separation and does not cause any disturbance to the smoke streamlines.
3) The smoke rake is placed right at the inlet of the Test section as against the contraction cone in conventional designs which eliminates the need for a specially designed contraction cone.

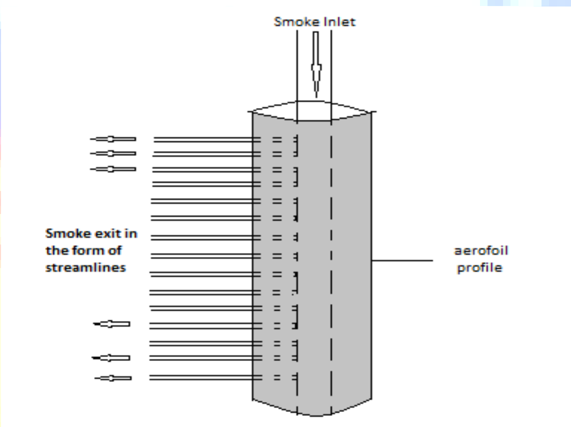

Fig 4.1(a): Proposed Smoke Rake

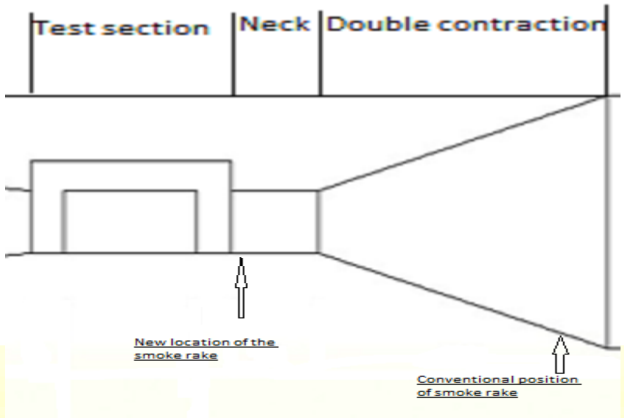

Fig 4.2(b): Showing New proposed and conventional positions of smoke rake

5. TEST RESULTS

The character of the flow field past an object is a function of:

1) Shape of the object
2) Size of the object
3) Orientation of the object
4) Speed of flow
5) Properties of the fluid

Since the fluid in the smoke tunnel is fixed, the effect of fluid properties cannot be demonstrated. Though the proposed economic design cuts down the cost, it does not compromise on the quality of test results. In order to prove this point some of the test results from our smoke tunnel have been shown:

1) Effect of the shape of the object on the flow field:

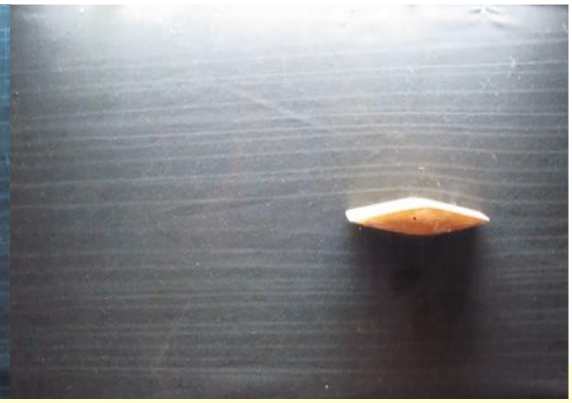

Fig 5.1(a): Flow past a cylinder of diameter diameter 20 mm

Fig 5.1 (b): Flow past an aerofoil of 20 mm

- The drag coefficient for an object depends on the shape of the object, with shapes ranging from those that are streamlined to those that are blunt.
- The flow past a cylinder of dia 20 mm is depicted in Fig. 5.1(a); where as in Fig. 5.1(b) the same cylinder is streamlined on both sides.
- As is clear from the figures, the size of the wake is much smaller in case of the streamlined body that the cylinder inspite of the fact that the diameter of both the objects is the same.

2) Effect of the size of the object on the flow field:

Fig 5.2(a): Flow past a cylinder of diameter 20 mm

Fig 5.2(b): Flow pasta cylinder of diameter 40 mm

- The flow past a cylinder of diameter 20 mm is depicted in Fig. 5.2(a); flow past a larger cylinder (diameter 40 mm) in Fig. 5.2(b).
- As is clear from the figures, as the size of the cylinder increases, the wake size increases and consequently the net drag on the cylinder increases.

3) Effect of the orientation of the object of the flow field:

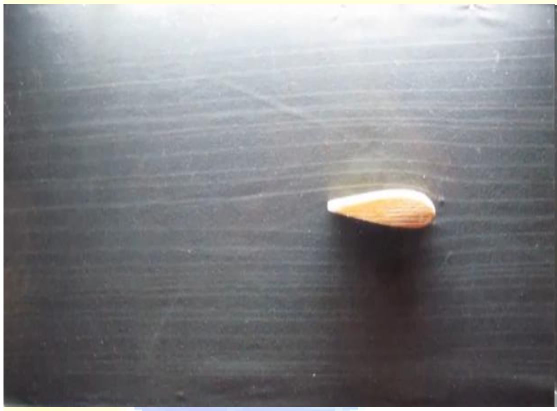

Fig 5.3(a): Flow past an aerofoil with Zero angle of attack

Fig 5.3(b): Flow past an aerofoil with non-Zero angle of attack

- The flow past an aerofoil at zero angle of attackis depicted in Fig. 5.3(a); flow past the same aerofoil ata non-zero angle of attack is depicted in Fig. 5.3(b).
- Over the front portion of the aerofoil the pressure decreases in the direction of flow-a favourable pressure gradient. Over the rear portion the pressure increases in the direction of flow-an adverse pressure gradient. If the adverse pressure gradient is not too great, the boundary layer fluid is able to flow into the slightly increasing pressure region without separating from the surface. However, if the pressure gradient is too adverse (because the angle of attack is too large), the boundary layer separates from the surface as indicated in Fig. 5.3(a).Such situations can lead to the catastrophic loss of lift called "Stall"

4) Effect of the speed of the flow on the flow field:

Fig 5.4(a): Moderate Reynolds number flow **Fig 5.4(b):** Large Reynolds number flow

- For moderate Reynolds no flows, the region ahead of the cylinder in which viscous effects are important are smaller, with the viscous region extending only a short distance ahead of the cylinder. The viscous effects are convected downstream and the flow loses its symmetry. Another characteristic of external flows becomes important-the flow separates from the body at the *separation location* .With the increase in Reynolds number, the fluid inertia becomes more important and at some location on the body, denoted the separation location, the fluid's inertia is such that it cannot follow the curved path around to the rear of the body. The result is a separation bubble behind the cylinder in which some of the fluid is actually flowing upstream, against the direction of the upstream

- For large Reynolds no flows, the area affected by the viscous forces is forced farther downstream until it involves only a thin boundary layer on the front portion of the cylinder and an irregular, unsteady, perhaps turbulent wake region that extends far downstream of the cylinder.

6. COST ANALYSIS

We have brought down the cost of each component and as such of the entire Smoke Tunnel by a good margin. The cost of this Smoke Tunnel (which is actually a low speed wind tunnel) was compared with low speed wind tunnel AF100 of TecQuipment designs. It was found that our Design was much more economical without compromising the quality of test results.

7. CONCLUSION

The proposed design proved to be economical in the sense that every single component of smoke tunnel was fabricated by keeping in mind the general average cost of projects in colleges like NITs and IITs in India. Individual component design such as the simple economic design of Smoke Rake was one of the examples discussed. The quality of the smoke was good and as such the test results. Wide variety of experiments on flow visualization could be performed. The Design of setup is compact and operates at meaningful Reynolds numbers. The setup saves a lot of money and time when compared to similar small/full scale-smoke tunnels.

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