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An Insight into the Flow Visualization in Wind Tunnel

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Abstract
The flow visualization and its ability to see flow pattern on and around a model often gives insight into solution to an aerodynamic problem. It can be divided into two broad categories, like surface flow visualization when the visualization media is applied to the surface such as tufts and oil flow etc. the second type is off surface such as smoke and streams. The present paper will deal with the visualization of flow past different types of models like flat plates, delta wings, elliptical cones and rectangular bluff bodies using different flow visualization techniques. The visualization of the flow was done using smoke wire technique. The smoke wire placed in the upstream side of the bluff body model. This helps to see the separating bubble from the frontal edge and ground vortices at normal incidence for both sharp and round edge models. This technique provided a clear influence of rounding of building edges on the separating sheer layers that form conical vortices. The influence due to change in the angle of incidence on the separation process for sharp and round edge model was found to be of interest. This laser light plane is generated by using a laser light source in conjunction with a lens system. This technique helped to study near roof region of a building model and wake region of delta wings and elliptical cones, considered important from pressure point of view as vortices are said to exist there which is a cause of severe suction. The study of the flow near the surface of the square plate model was carried out by using chalk powder suspended in kerosene oil and sprayed on the model. The pattern of the flow observed revealed direction of surface streamlines and features like separation of flow, which results in interpretation of flow. The purpose of this paper is to highlight the importance of different flow visualization techniques and its usefulness in depicting the impact of flow on different types of models and its application in day to day life. This study will help to understand the flow field which is causing different type of pressures on the rooftop building models, flat plates and elliptical cones.

Keywords: flow visualization, vortices, delta wings, elliptical cones, bluff body, flat plates, smoke wire

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INTRODUCTION

Flow visualization is an excellent means of examining the flow patterns around a body or over its surface. The flow is visualized by introducing the dye smoke or pigment into the flow into the area under investigation. The primary advantage of such a method is its ability to provide a description of the flow model without a complicated data reduction and analysis. Smoke flow visualization (Bradshaw, 1970) and (Rae and Pope, 1984) involved the injection of streams of vapor into the flow. The vapor follows filament lines (lines made of all the fluid particles passing through the injection points). In steady flow, the filament lines are identical to streamlines. Lines everywhere are tangent to the velocity vector. Therefore, the smoke flow visualization reveals the entire flow pattern around a body. It is difficult to exaggerate the value of flow visualization and its ability to see flow pattern on a model often gives insight into a solution to an aerodynamic problem. Flow visualization can be divided into two broad categories, the first is surface flow visualization when the visualization media is applied to the surface such as tufts and oil flow etc. the second type is off surface such as smoke and streams. There are four methods of recording the flow visualization. The first and the best, which is the least permanent method, is for the scientist and engineer is to observe with his eyes. Because of the depth perception, one can see a Three-dimensional picture. The other three common methods of recording the flow visualization or by film either still or movie, television camera, video and magnetic tapes. It must be realized that all three of these methods are using a two-dimensional medium to record a three dimensional phenomena. This is especially fine when using smoke or helium bubbles to trace flow stream lines past the models. All three of these methods are used in either black and white or color. The photographic methods while recording takes more time for developing and printing stills when compared to video yield higher resolutions. The interest in these studies is to understand and influence the flow in wake region like minimizing the vortices formation behind the flat plates, elliptical cones and also the building models. These will severely affect the pressures developed which adversely impact the buildings and other structures causing damages.

Flow Visualization Techniques

The present paper will deal with the visualization of flow past different types of models like flat plates, delta wings, elliptical cones and rectangular bluff bodies using the following: Smoke wire techniques,

Laser light illumination techniques, and Surface flow visualization techniques.
The result obtained is discussed considering the importance of different techniques.

Flow Visualization Using Smoke Wire Techniques
The visualization of the flow past the building models was made possible by using the above technique used by Batill and Mueller. It was further improved by Stahl and Mahmood. The procedure involves brushing a thin wire which then forms small droplets. Heating the wire evaporates the oil with each droplet providing a fine streak line in the flow. Under proper illumination, the smoke streaks appear bright and can be observed and photographed. This technique requires a fine wire about 0.1 mm in diameter of nickel chromium steel and suitable oil that can vaporize quickly and a DC current to heat the wire, as it is very useful in studying separation especially in smooth and nominal boundary and turbulent flows. The smoke wire placed in the upstream side of the wire helps to see the separating bubble from the frontal edge and ground vertices at normal incidence for a bluff body (Fig. 1a, 1b). For both sharp and round edge models. For oblique incidence of 25 degrees and 45 degrees, a smoke wire that was placed at a suitable position to note the separation of sheer layer in the immediate vicinity of the leading edge corner (Fig. 2a, 2b) where high suction pressures are developing. This technique provided a clear influence of rounding smooth edges on the separating sheer layers that form conical vertices. The influence due to change in the angle of incidence on the separation process for sharp and round edge model was found to be of interest.

Flow Visualization α = 90°
The results for angle of incidence for smooth flows are shown in figure 1a, 1 b. These indicate that for a sharp edge model, the flow incidence on the front surface of the model divides into two parts. Part of the flow goes up and separates from the frontage. With a large bubble and a recirculation closer to the leading edge and the rest of the flow dissents down and forms a vortex near the ground. In the model with the rounded edge, the flow does not have a sharp separation but a long bubble with a height smaller than that noted for the sharp edge model. The balance flow goes down forming a vortex close to the ground in a way similar to noted in the case of sharp edge model. The difference between the smooth and turbulent flow is visible from the separation of flow from the frontal edge. The height of the separation bubble is comparatively small in turbulent flow than the smooth flow.

Flow Visualization at α = 45°, 25°
As the region near the leading edge corner is considered critical and important since maximum mean and peak suction pressures were recorded at whole number 50205 (Texas tech test building nomenclature) smoke wire technique was utilized to observe the flow past the region. Batill and Mueller studied the transition in the flow on an airfoil using this technique. Mahmood also successfully applied this technique to study the flow past flat plates at various angles at incidence of 45 degrees the smoke streak incidence on the sidewalls at a distance of about 15 – 20 % of the length of the wall goes up and separates to form large separation bubbles (bump). on the top surface of the sharp edge model as evident in figure 1 c. the remaining flow move down resulting in a recirculation of the flow which persisted all along the length of the wall. But as the rounding is increased the size of the bump became smaller indicating the influence of rounding at the specific location. A bump smaller in size was noted for a round model with a radius of 5 mm. for a model of radius 10 mm the smoke streaks remain almost attached to the roof and just slide over curved roof surface with a minimum possible separation as shown in figure 2a,2b. Similar changes were noted for the flow at an angle of 25 degrees. For this incidence angle, the sharp edge model shows more separation and height of the separation of the vortex sheets decrease with increase rounding as evident in figure 2a, 2b.

For a sharp edge model a clear separation was visible at station 1 that is around 15-20% observed distance. But when round edge model was placed , The height of separation reduced proportionally to the magnitude of rounding especially for R= 10mm model where the flow remain attached from sidewall to top surface as shown in figure 2b. This is in line with the observation made in smooth flow conditions, and expected to influence the pressures that are developed on the top surface of models. Since the influence of rounding was visible on both flows at oblique and normal incidence. Its influence on the pressure characteristics was investigated and compared in both the cases.

Flow Visualization Using Laser Light Illumination Techniques
A smoke probe was utilized to generate heavy smoke upstream side which then passes over the model. A section of the flow was made visible by using a laser light sheet. This laser light plane is generated by using a laser light source in conjunction with a lens system. This technique helped to study the flow on the top of the model. The near roof edges region considered important from pressure point of view as corner vertices are said to exist there which is a cause of severe suction. The presence of corner vertices and the changes that take place in them could also be studied. Still pictures at different stations were

obtained by moving the laser light plane. This technique was used in all flow conditions.

Flow Visualization Smooth Flow at α = 45°

The flow was visualized at 2 stations on the model top surface. Figure 3a and 3b show the section of the flow near the leading edge at station 1. Whereas 3c and 3d show the section of the flow at station 2 which was at about 50% figure 3a and 3c show that there exists a concentrated vertices springing from both the leading edges at station 1 and 2 respectively in the case of sharp edge models. Bienkiwickz and Sun also reported a similar observation on a sharp edge cubicle model. When surface flow visualization was carried out in a turbulent boundary layer flow. Figure 3b shows some separation and rolling at station 1 for a round edge model with edge radius of 5mm with a small vertex formation whereas at station 2 a big vortex formed as shown in figure 3d. This had a diffused or burst nature and could be observed during flow visualization. For a model with a further rounded edge of 10mm no separation was noted at station 1 whereas proceeding towards the model end to station 2, formation of vortex was noted which can be seen in figure 3d. This has a loose core and a burst nature. A similar vortex with a loose core is observed for cylinder sharp edge delta wings at high incidence.

Flow Visualization Past Elliptical Cones And Delta Wings

As reported in the literature that the symmetry of vortex formation and the degree of asymmetry on elliptical cones is influenced by the thickness of the ellipses. Under theoretical predictions about the degree of asymmetry was also made in order to study this phenomenon different elliptical cones whose base height to width ratio varied between 20-80% was taken . The model was placed in the wind tunnel using a suitable fixture. A smoke was generated upstream side of the model using a smoke probe. The laser light sheet illumination technique to find the characteristics. The degree of asymmetry would be found when the plane of observation is bit normal to the axis of the cone. Similar results were reported on circular cone where it was possible to observe an asymmetric flow change into almost symmetric one when a fin was fixed onto the cone (Figure. 4).

Experiments were conducted to study the symmetry of vortex formation on sharp edge delta wings of aspect ratio A = 0.56 it was observed that up to certain angle of attack , symmetric vortex formation takes place as can be seen from Figure 5. These vertices looked quite concentrated sitting on the wing. When the incidence angle was increased one vortex got burst and further increase in incidence angle resulted in the bursting of both the vortices. The bursting of one of the vortices can be observed during flow visualization. A study by terry et al shows the use of laser light illumination in visualizing the flow past delta wing.

Surface Flow Visualization Technique

The study of the flow near the surface of the square plate model was carried out by using chalk powder suspended in kerosene oil and sprayed on the model. Figure 6a shows the setup for surface flow visualization. When the flow passes the model the chalk and Kerosene mixture settles as per flow lines. The pattern of the flow observed revealed direction of surface streamlines and features like separation of flow from the surface Figure 6b.

CONCLUSIONS

Flow visualization is considered as an important tool to understand the nature of flow field. Its proper utilization will provide reasonable information of the flow characteristics. The above methods mentioned are not the only ways to understand the flow but the results obtained using above methods highlights the usefulness of these techniques. All the above methods are useful only in controlled atmospheric conditions like wind tunnel and a lot of expected variances are possible when a similar adverse wind environment that exist outside in open atmosphere.

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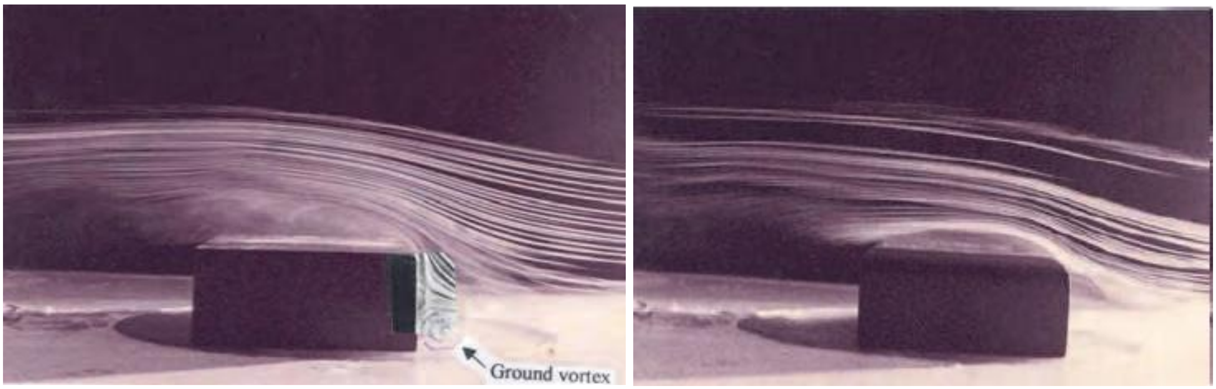
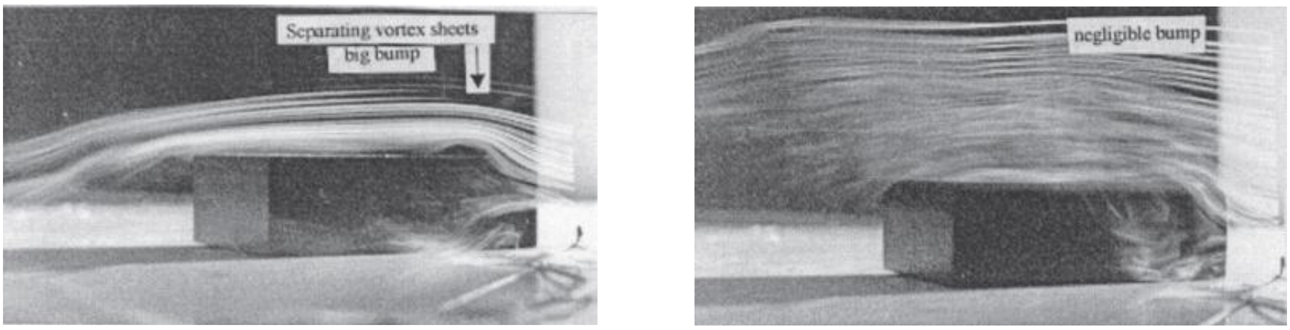
Figures



(a) (b)

Fig. 1. Flow visualization using smoke-wire technique (smooth flow condition). View from front.

a. Sharp edge model α= 90°
b. Round edge model R= 10 mm, α= 90°



(a) (b)

Fig. 2. Flow visualization using smoke-wire technique (smooth flow condition). View from front

a. Sharp edge model **α**= 45°
b. Round edge model R= 10 mm, α= 45°

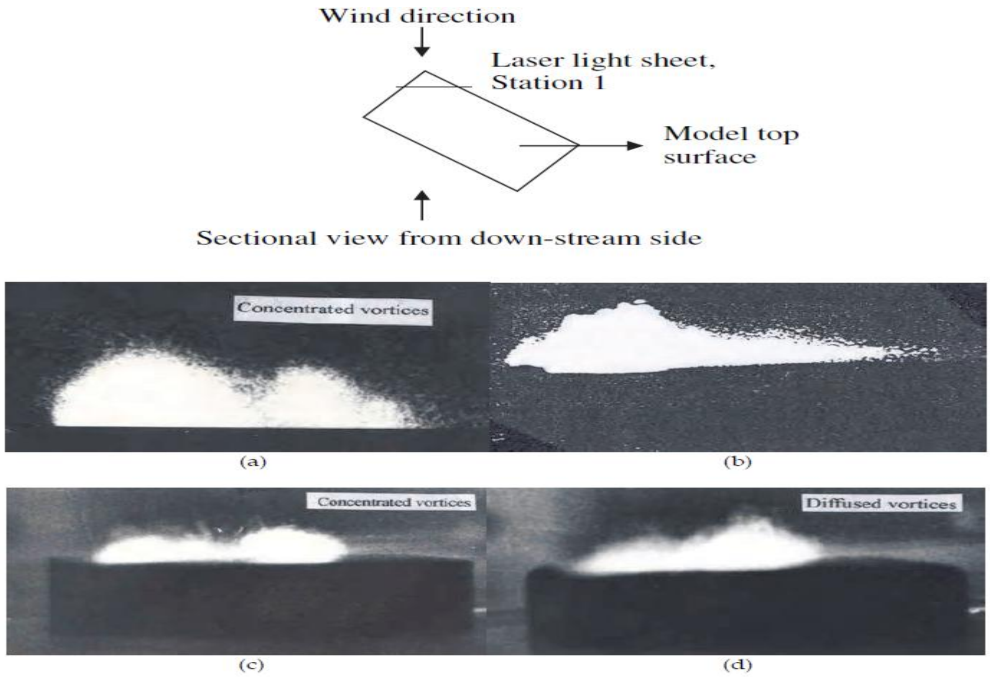


Fig. 3. Flow visualization (top surface) using laser light sheet illumination technique α= 45°.
(a) Sharp edge model, (b) round edge model, *R* = 10.0 mm station 1 (15% of length), (c) sharp edge model, (d) round edge model, *R* = 10.0 mm station 2 (50% of length).

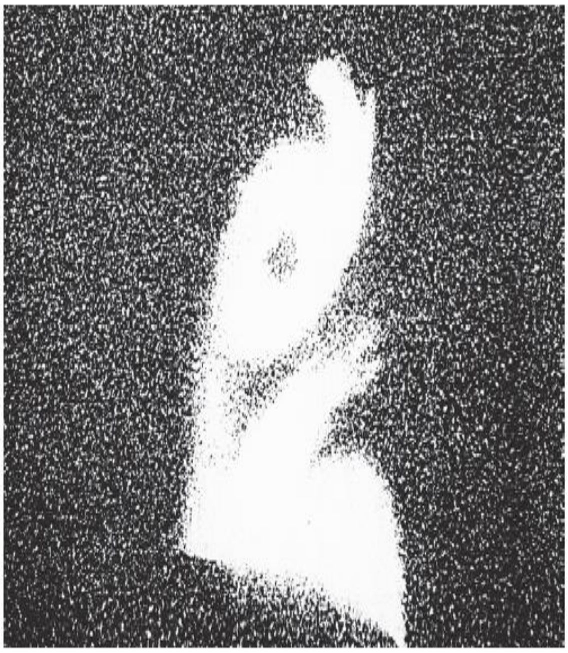


Fig. 4. Vortex formation behind elliptical cone thickness ratio=0.65, Reynolds number =132,000

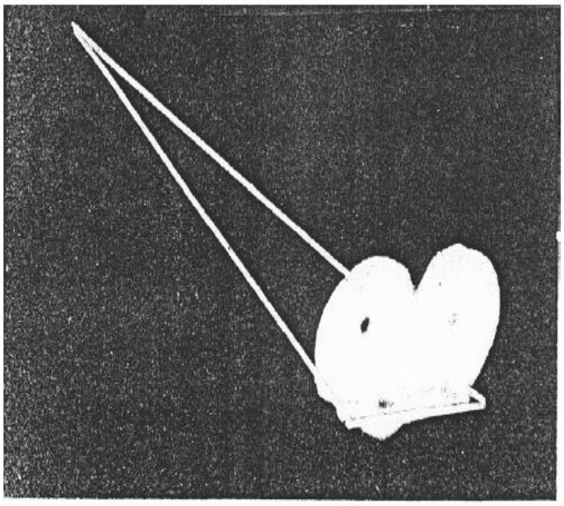


Fig. 5. Vortex formation behind Delta wing Aspect ratio=0.56, Reynolds number =132,000, **α** =30°

Fig. 6a. Surface flow visualization setup

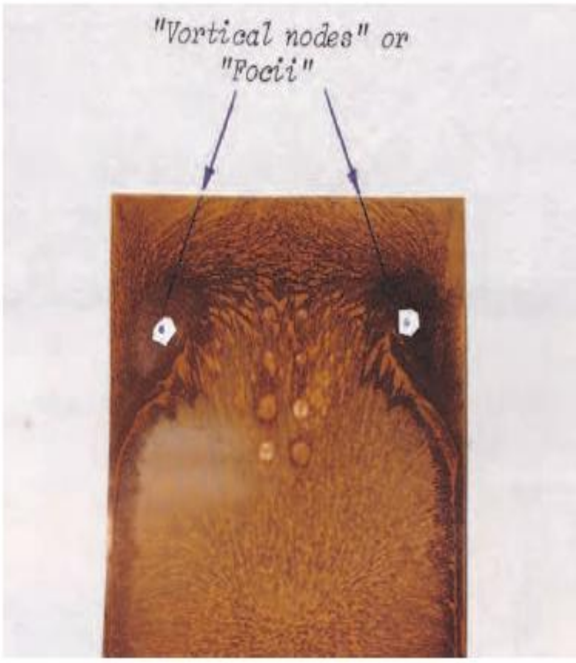


Fig. 6b. Surface flow visualization on wake side of flat plate at α= 28°