School of Aerospace Engineering

AE3051 Experimental Fluid Dynamics

FLOW VISUALIZATION

Objective

The experiment is designed to introduce the student to some of the techniques and approaches used in flow visualization. It is also intended to have the student gain experience in observing flows and drawing conclusions about them from the observed behavior.

Background

a) The Aerodynamics Problem

Aerodynamics is a difficult science because the medium with which the aerodynamicist works (air) is not visible under normal conditions. Valuable insights into the physical features or behavior of an air flow could be achieved if the entire flow field or certain streamlines or regions could be seen by the eye or by a recording device. If the flow could be made visible by some kind of flow visualization technique, then it would be possible to observe flow phenomena which are essentially inviscid (e.g., vortical flows, flows distant from surfaces) as well as those phenomena which are dominated by the effects of viscosity (e.g., boundary layer flows, separation). In addition to qualitative observations, under certain conditions it would be possible to make quantitative measurements from flow visualization data as well. For example, a measurement of the distance between streamlines in a 2-D incompressible flow provides information on velocity ratios in the flowfield.

b) Flow Visualization

Flow visualization in air may be broadly divided into surface flow visualization and off-the-surface visualization. Surface flow visualization involves tufts, fluorescent dye, oil or special clay mixtures which are applied to the surface of a model. Visual inspection of such tufts and coatings as a function of time, or after some time, will give valuable information on such things as the state of the boundary layer (laminar or turbulent), transition, regions of separated flow and the like. It must be remembered in such visualization that what is observed on the surface is not always indicative of what is happening away from the surface.

The second type of visualization is off the surface and involves the use of such tracers as smoke particles, oil droplets or helium-filled soap bubbles. The visualization medium must faithfully follow the flow pattern or it is not conveying the correct information. The smoke particles and oil droplets are very small and are light enough that they will follow the motion of the flow; the soap bubbles are small and are filled with helium to make them neutrally buoyant. Each of these methods requires appropriate lighting and some device for recording the image such as a still or video camera. If the flowfield is illuminated in a plane by appropriate masking of the light source it is possible to examine discrete sections or slices of the flow. For example, a laser light beam can be expanded into a thin sheet by passing it through a cylindrical lens. This sheet then can be used to illuminate any cross-section of an airflow that has been seeded with particles. The laser light will reflect from the particles, but dark images will be observed where there is an absence of particles, such as in the center of a vortex. A vortex core is almost void of particles since they have been spun out by the action of centrifugal force.

In addition to flow visualization using tracer particles or surface coatings, optical means can be used to visualize flows or flow features. For example, laser light systems are used to produce holographs that can be used for density measurement and flow visualization even at low subsonic Mach numbers. For compressible flows, Schlieren systems, which respond to density gradients, are used to optically determine the locations of shock waves and expansion regions but they will not accurately provide the values of flow properties. An optical method that will accurately yield the magnitude of the density anywhere in the flow is based upon the principle of interference. A light ray is split into two optical paths, one passing through the test section and the other through a reference air column. The two beams then are merged and refocused on a screen. The screen shows areas of light and dark (fringes) because there is a phase difference between the two beams which depends upon the difference in the lengths of their light paths. By taking pictures with and without flow in the test section, fringe shifts will be observed from which an equivalent change in optical path may be determined. This change, in turn, can be related to a change in density so that contours of known density in the test section can be found. This optical measuring device is called an interferometer.

Flow visualization is also carried out in water flows because the visualization is easier, although it must be recognized that the Reynolds number of such a flow may be quite different from that of the air flow under study. The water may be injected with dyes of different colors either through small orifices in the model surface or upstream so as to act as streamline tracers. Regions of the flowfield also may be visualized by generating small hydrogen bubbles in the water which will move with the water flow. In this technique, a fine wire cathode is positioned in the water and connected to a DC power supply; the anode is located elsewhere in the water. The circuit thus is completed through the water (the water conductivity can be enhanced by the addition of a salt, for example, if necessary). When the circuit switch is closed, small hydrogen bubbles are emitted from the wire cathode which then are swept along with the water flow. These bubbles may be viewed with proper lighting.

c) Flow Visualization Devices

Smoke Tunnel

The first flow visualization device to be used in this experiment is the smoke tunnel. This is a two-dimensional wind tunnel with a test section which is 48 inches high, 36 inches long, and 2.5 inches deep. The sides of the wind tunnel are made of glass. Air is pulled through the test section at a low velocity (maximum 29 ft/sec) by means of a small blower at the exhaust end of the tunnel. The test section is lit with floodlamps from the top and bottom.

Smoke is generated in a reservoir, which is located in a compartment beneath the wind tunnel. Oil in the reservoir saturates a wick wrapped around a wire heating element that vaporizes the oil. An air tube, which originates from the downstream end of the blower, forces air through the reservoir and picks up the oil producing a fine smoke. The reservoir is connected to a streamlined feeder pipe that stands vertically in the middle of the flow at the upstream end of the wind tunnel test section. This feeder pipe spans the height of the test section and includes 25 small tubes spaced 3/4 inch apart that protrude from the downstream side of the feeder pipe. Smoke emerges from these small tubes and enters the main airstream, so that at the test section an observer sees the flow streamlines as discrete narrow bands of white smoke.

Various models may be mounted in the test section and the resulting flow pattern can be observed or recorded photographically. The flow velocity is kept low so that the smoke particles in the freestream will stay in layers or lamina and maintain their identity; smoke in turbulent flow tends to dissipate and makes observation difficult.

Water Table

The second flow visualization device is a recirculating water tunnel with a test section which is 17.5 inches wide, 49 inches long and a few inches deep. Two reservoirs, one located at each end of the table, are connected by a pump. In addition, one end of the table is slightly higher than the other, thus producing a flow of water across the table. The upstream reservoir is filled with glass balls so as to produce a uniform flow coming out of it. The color dye technique mentioned above will be used to visualize the flow in a variety of configurations.

PROCEDURE

Smoke Tunnel

1. On the front panel, turn the main power **on**, then turn **on** the power for the lights and smoke. Allow the smoke generator to start producing the smoke (~5-10 seconds), then turn the blower **on**.[1] To start, set the speed control about halfway - you will not need to know the air velocity, but it varies approximately linearly with the setting of the speed control with a maximum velocity of 29 ft/sec.
2. Before opening the front door/window of the test section, turn the smoke generator and blower **off**.[2] Open the front door of the test section and mount the following models in turn on the attachment disk:

   a) a cylinder;

   b) a symmetrical airfoil without flap - at a minimum, vary the angle of attack from a small value through stall;

   c) an airfoil with flap (the flap angle is controlled by turning the knob marked *Aux 1* on the front panel) - at a minimum, set the airfoil at a moderate angle of attack and vary the flap angle from 0 to 45 degrees;

   d) a finite wing - set at a moderate angle of attack before installation; and

   e) a 3-D wing tip.

   This is a flow visualization experiment. That means you should feel free to adjust the wind tunnel speed and geometry of the models in order to "see" what happens as you change conditions.
3. When the observations have been completed, turn **off** the smoke first, then the lights. Allow the blower to run for about five minutes to clear the smoke out of the tunnel, then turn **off** the blower and the main power.

Water Table

1. Turn the main power switch **on**. Turn the water pump **on** . Make sure that you do not have any leaks or that the water does not spill over the top.

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[1]If needed (if the smoke flow begins to disappear), you can routinely turn the blower off to allow the smoke generator time to regenerate smoke. Only do this if the smoke flow is hard to see; otherwise, you will just end up filling the room with smoke.

[2]Again, if the smoke flow is hard to see, you can leave the smoke generator on when you turn the blower off.

Boundary Layer Flow

2. Insert a flat plate parallel to the water flow. Take a float with a little cruciform on the end and place it in the free stream. Observe its motion. Now take the same float and place it in near the flat plate. Again observe its motion. Try to note if the float rotates.
3. Take the syringe filled with food dye and inject a line of dye upstream of the flat plate (somewhere below the surface of the water), and perpendicular to the flow. Observe the path marked out by the dye as it flows downstream.

Jets and Other Flows

4. Use the filler hose to create a jet of water into a coflowing stream of water (you will probable need to open the drain on the table, remove some water first, and leave the drain open while the hose is on).
5. Take the syringe filled with food dye and (slowly) inject the dye into a region at the hose outlet, just at the edge of the water jet. Observe the path marked out by the dye as it flows downstream.
6. Try injecting the dye at other locations at the hose outlet and again observe the dye as it flows downstream.
7. As time permits, feel free to try other flow arrangements. Other interesting flowfields include stagnation streamlines approaching a bluff body (e.g., a cylinder), wakes and airfoils.
8. When you are done, make sure to turn **off** the pump and the main power supply.

DATA TO BE TAKEN

No quantitative data will be taken for any of these flow visualization runs, although such data could be gathered if necessary. Here, the emphasis is on observing the behavior of the flow and extracting conclusions from those observations. Each student should come prepared to make notes and draw rough sketches documenting what is observed; these sketches and notes will comprise the data from the experiments. Do **not** rely on your memory - keep a careful log as the laboratory progresses.

DATA REDUCTION

Since no quantitative data will be taken, no data reduction is required.

RESULTS NEEDED FOR REPORT

Below are discussion questions that you should address in your report. They will, in part, require that certain flow features be observed during the experiments. These questions are in addition to those listed in the supplemental handout. Each answer to the questions below must be based on a figure (introduced in the Results section of your report). These figures should be sketches (free-hand is okay, but carefully done) of the flow patterns that were observed. Therefore, carefully observe the major flow features and take notes during the experiment. Also, make rough sketches to be copied or improved upon for your report.

<u>Smoke Tunnel</u>

1. **Cylinder** - Contrast what was observed as the airflow went around the cylinder with the potential flow prediction for the flow around a cylinder. Why is there a difference? What is the effect of this difference on the aerodynamic performance of a cylinder?
2. **Symmetrical airfoil without flap** - Describe the flow behavior you observe as the angle of attack is increased from a small value to a value above the stall. Pay particular attention to the behavior of the streamlines nearest the body as a function of angle of attack.
3. **Airfoil with flap** - With the airfoil set at a moderate angle of attack, vary the flap angle from zero to 45 degrees and describe the changes in the flow around the airfoil/flap combination that are observed as a function of flap deflection angle.
4. **Finite wing at angle of attack and 3-D wing tip** - Describe the behavior of the streamlines near to tip of the wing and downstream of the wing. What does this behavior represent physically?

<u>Water Table</u>

1. **Flat Plate Boundary Layer: Dye –** What shape did the dye, which started out looking like a "straight" line, take on as it moved downstream along the flat plate? Why does this occur?
2. **Flat Plate Boundary Layer: Float –** Contrast the movements of the float when placed near the wall with its movements when placed in the freestream. What does its movement tell you about the vorticity in the freestream and in the boundary layer?
3. **Jet into Coflowing Stream –** What type of flow features were traced out by the dye when it was injected at the interface between the water leaving the hose and the water in the table? How does this compare to the flowfield that would be predicted by potential flow theory?