Design of a Setup for Flow Visualizations

Design Team
Caitlin Curtis, Andrew Dunbar, Shu Yi Zhou

Design Advisor
Prof. Mohammad Taslim

Abstract
The objective of this project was to design a bench-top flow visualization device for the Mechanical Engineering Department of Northeastern University. The device will be used primarily for education and research within the department. The device is of fairly low cost, accurate, easy to use, and multifunctional. Several types of flow visualization were initially researched to provide insight on the best type of visualization and flow medium available. From this process, the smoke wire technique was selected. Air was selected as the flow medium and a pair of twisted 0.005” nichrome wires was chosen for the smoke-wire. The design was refined and analysis of results from testing different smoke-wire materials and configurations has been completed. The device has been completed and the results have been compiled.

For more information, please contact m.taslim@neu.edu.
The Need for Project

The current flow visualization systems are inadequate for use in the engineering department. Many of the existing systems that are used to visualize flow are bulky, expensive, and are limited to the study of one type of flow, such as the system shown in Figure 1. Currently, no single, portable and low-cost unit is available on the open market that can be used to teach and research different types of flow. The mechanical engineering department requires a mobile and reliable device to aid in fluid flow and heat transfer courses. This set of criteria could not be found in an existing flow visualization setup so the group was tasked with creating the system.

The Design Project Objectives and Requirements

The objective of this project is to develop a flow visualization system that is inexpensive, multifunctional and convenient for use in the engineering department. Design Objectives

Air is the preferred flow medium both for cleanliness and ease of use. Some suggested applications of the device are interaction of flow in a channel with obstructions, flow over blunt bodies, flow over airfoils, jet interactions with the target wall, opposing jets in a plenum, film cooling air interaction with the flow over a surface, recirculating zones and flow over concave or convex surfaces.

Design Requirements

Critical requirements included size, safety and cost. The product had to fit on a single cart and be portative enough for one person to maneuver with a cart but be large enough for multiple people to see the flow visualization going on within the system. The system’s main function is for research and teaching within the mechanical engineering department, and therefore there is a requisite safety that the system had to abide. Minimizing cost was crucial because the present system is necessitated by the expense of the other available products, such as that in Figure 2.
Design Concepts Considered

Several ways to visualize flow were considered and evaluated throughout the course of this project. The flow visualization methods fall into three categories: particle image velocimetry (PIV), optical methods, and streamline visualization.

Particle Image Velocimetry (PIV)

The most precise, comprehensive method of visualizing flow is particle tracing. There are many particle tracking methods but particle image velocimetry (PIV) is the most widely used in the field. This method uses highly sophisticated software and extremely sensitive sensors to follow tracer particles which are introduced into the flow. PIV produces highly accurate quantitative measurement but is not a robust system for qualitative flow visualization. An image produced by PIV can be seen in Figure 3. The precision setup required for PIV is inherently cumbersome and therefore does not provide the user with the flexibility to easily change flow setups. It also requires lots of processing power to analyze and render the images captured by the camera into images that can be comprehended. These factors make PIV a large time, labor, and financial commitment.

Optical Methods

In some cases, flow can be visualized and viewed with the naked eye. From physics it is known that changes in the pressure and thermal energy of a body of gas will lead to a change of its refractive index. These changes can be visualized using optical methods. By shining a laser beam through or creating a shadow of the flow, the changes in the refractive index can be seen, as in Figure 4. Optical methods are an easy and effective way to visualize flow two dimensionally. This method is cheap (only costing as much as a laser beam generator) and has long been effective. The inherent problem associated with shadowgraphs and other optical methods has to do with the captured image versus what is actually going on in the flow. A three dimensional flow is projected onto a two dimensional surface and that image is then captured for analysis. The third dimension is lost. These changes, while accurately being recorded in two dimensions, actually occur in three dimensions, and therefore a level of accuracy and understanding of the flow is lost.
Streamline Visualization

Streamline visualization works by introducing smoke or dye into the main flow medium, resulting in streamlines, such as those in Figures 5 and 6. The smoke-wire method involves stretching a thin wire across the entrance of a test section, perpendicular to the flow direction. The wire is coated with some type of oil via brush or other delivery system. An appropriate amount of electrical current is then passed through the wire leading to Joule heating. The liquid will bead up on the wire, forming a series of small droplets at even intervals. The resulting thermal energy in the wire evaporates the individual droplets. When performed in a flow, the vaporized liquid is carried with the flow, creating streamlines. A fog or smoke machine in conjunction with a smoke rake could also be used to visualize the flow. The resulting visualization would not greatly differ from that of the smoke-wire method, but it would not create the same concise stream lines. This is sufficient for the teaching of basic physics and flow mechanics classes as well as macro-sized flow research.

Recommended Design Concept

The streamline flow visualization method was chosen as the preferred system.

Design Description

For the final design, a rectangular tunnel was created out of .5” thick pieces of clear acrylic. The cross sectional area of the tunnel is 8” x 8” and its length will be 40”. Metal ducting is attached to this box and routed downward underneath the tunnel where it will attach to the blower. The blower provides a source of suction; it will pull air through the tunnel and direct it towards the floor. Foam and honeycomb protect the flow visualization from any disturbances going on outside the test section. The final design is seen in Figure 7 to the left. Within the tunnel with resides a stainless steel smoke wire frame (Figure 8). This frame will be used to slide the smoke wire throughout the test section and hold the electrical components required for heating. Inside the wire-tensioners will be a small tension spring used to keep the wire tight during heating. The power is supplied to the smoke wire frame via a system of copper tracks on the base of the test section. This allows the smoke wire frame to slide within the test section. The electrical components primarily lie in the base of the system.
Analytical Investigations

Maximizing the Reynolds number in the system gives the user the most flexibility with regard to the experimentation. With this in mind, the group calculated the maximum velocity that could be passed over the smoke wire without producing Eddy currents. The voltage and current going through the smoke wire was determined to maximize the burning time of glycerin. The voltage and current being passed through the system was analyzed in regard to the safety. It was determined from this calculation that the hatch design would include a failsafe which would not allow power to the system while the hatch is open.

Experimental Investigations

The final substrate liquid and smoke wire material needed to be tested in order to be used. Glycerin was tested to confirm that it produced concise and strong streamlines. The group explored the addition of metallic powders to the glycerin to increase the duration of the streamlines. While the streamlines were slightly extended, the powders left a residue on the test section as seen in Figure 10, making use inconvenient. Based on initial research the group also tested the possibility of stainless steel and Nichrome smoke wires with a strand and twisted configuration. The twisted nichrome wire maximized the duration of the streamlines and was incorporated into the final design to produce images like Figure 11.

Key Advantages of Recommended Concept

The streamline flow visualization method provides the most function and ease of use within the critical design criteria. The device is also accurate and most of all safe to use within the department.

Financial Issues

The cost of the acrylic material and camera were the largest purchases. The acrylic material was critical to the design due to its strength and quality. The cost of the acrylic was $155. A high speed camera was also procured so the group could record the images produced by the system at the cost of $330.

Recommended Improvements

Demonstration in a classroom is vital to understanding the patterns that develop and the possible issues that arise as a result. Even minute changes in an airfoil cause the flow to change drastically. Additional development of the airfoils may provide the user with more flexibility within the system.