Ink Dot Technique of Flow Visualization for the Undergraduate Fluid Mechanics Laboratory

William S. Janna[1]

Abstract—The ink dot technique consists of applying ink dots on a surface of an object that is placed in a low speed wind tunnel. The dotted area is then sprayed with oil of wintergreen (synthetic methyl salicylate) to coat with a thin but continuous film. The ink dots dissolve and diffuse into the oil. As air moves past the object, the dissolved ink dots trace out a streakline. The objective of this study was to find an alternative method of applying ink dots, and obtaining streamlines of flow about a body. The improved method consists again of applying a matrix of ink dots to paper. The dots are applied to printer photo paper and sprayed with alcohol.

Keywords: Flow Visualization; Ink Dot Technique; Fluid Mechanics; Streamlines

INTRODUCTION

Flow visualization methods have been developed and used extensively to demonstrate flow patterns around cylinders, around wings, through orifice meters, about turbine blades [Anapu, et al, 2], and much more. Various techniques have been use including hydrogen bubble generation, dye injection, and more recently, the ink dot method.

Da Vinci provided the earliest known reference to the significance of vortices in fluid motion when he sketched swirls of water behind a bluff, Figure 1. His analysis of the vortices and eddies was very close to the much later theory describing the same phenomena; i.e., Richardson's Cascade. Both descriptions recorded by Da Vinci are nearly identical to those written much later.

Atraghji [1] in 1980 presented what was introduced as the Oil Dot Technique, similar to what is described in this study. Azar [3] used flow visualization methods to make measurements in electronics cooling. Khemani [4] used flow visualization techniques to generate pathlines, streaklines and streamlines. Ishihara et al [6] used the oil film method to visualize laminar separation in various flows. Langston [7] provided a description of this new method, and Loffelmann [8] and Merzkirch [9] both published treatises on flow visualization in general. Settles [10] describes modern developments in flow visualization.

NARRATIVE

The search for a reliable, easy to use, apparatus for flow visualization has led to this study. It was desired to assemble meaningful and popular experiments using the wind tunnel in the fluid mechanics lab. The lab has experiments in measuring fluid properties, measuring the force exerted by a jet of liquid, measurement of flow rate in pipelines, and more. Missing from the list is an experiment involving measuring lift and drag, with an accompanying method of generating streamlines about the object of interest.

[1] Department of Mechanical Engineering, University of Memphis, Memphis, TN 38152, wsjanna@memphis.edu

Various devices have been used to obtain streamlines of flow about an object. A number of texts showing flow patterns have been published and are available on the internet. Looking at a photograph is good, but a student generating his/her own streamline patterns is better.

Past experience with different pieces of equipment have yielded unsatisfactory results. A hydrogen bubble generator used to obtain streamlines about an object is difficult to use. It requires special and intense lighting, and is inconvenient to set up. Recently, Armfield has marketed a flow table that can be used to obtain streamlines of flow. This device consists of a flat piece of glass oriented horizontally, with basins attached at both ends. The upstream basin fills and water flows from there over the glass in the form of a thin sheet of liquid, and then to the downstream basin. Dye is admitted to the flat stream of water from a dozen or more submerged injectors, which are shaped like hypodermic needles. The dye used can be anything from potassium permanganate to food coloring. A small plastic tank is filled with dye, and the dye then flows from this tank to a pipe that contains the injectors.

Problems with this apparatus are numerous. The flat piece of glass is painted white on its underside, and black grid lines are painted over the white paint. The grid lines interfere with what the viewer hopes to see. Vibrations from the inlet tube (or pipe) to the upstream basin make their way into the water. The downstream basin receives water, and as water splashes downward, this also contributes to vibrations. The vibrations cause the lines of dye to become wavy.

The injectors must all be identical and produce identical lines of dye. This is not the case with the injectors supplied with this apparatus. Moreover, when the apparatus is turned off, the dye dries in the injectors once the water level recedes, and they remain clogged until some means (mechanical or otherwise) is used to clear them out.

To obtain streamlines from this apparatus, a camera must be used to obtain a photograph. Positioning the camera several feet above the glass is difficult, and once the apparatus is turned off, the streamlines are gone.

Most recently, the ink dot method has been developed and used to obtain streamlines. Advantages of using this method are numerous. The ink dots are applied to photo paper using an inexpensive marker. The streamlines are generated with a wind tunnel and air rather than with water. When the wind tunnel is turned off the photo paper provides a permanent record of the streamlines. Any object can be used in the tunnel, and this is demonstrated here.

The students can obtain streamlines of flow about an object of interest in a very short time. Steady state in the wind tunnel is achieved in moments. There are no vibrations to contend with that cause "waviness" problems. So in a relatively short time in the fluids lab, a student can measure forces exerted on an object of interest, and obtain corresponding streamlines of flow about that object.

FIGURE 1 *Da Vinci's (c1500) water pouring into a pool .*

METHODOLOGY

With regard to the experiments just described, it should be noted that students find flow past a cylinder rather mundane, or insipid. However, a model car or truck can be used in the wind tunnel, and an object of this type generates much interest.

Shown in this paper are photographs of objects used by students in developing this experiment for the fluid mechanics laboratory.The history of the ink-dot technique may be found in several sources. The traditional method makes use of permanent ink along with oil of wintergreen on contact paper. It was desired to incorporate this method in the undergraduate fluid mechanics laboratory for flow visualization purposes. It was necessary to obtain oil of wintergreen, and a local source was found, but the cost of the oil was prohibitive if this method was to be used by all students in the fluid mechanics laboratory. The oil was ordered and used, however, in order to become familiar with the method.

Ink, Paper, and Solvent

Many test were performed using various combinations of paper, ink and oil/solvents including: Engineering graph paper; Dura-Mark marker; WD40 and more. Various problems were encountered: paper too absorbent; ink dots smeared, etc.

Adhesives

A problem encountered was in securing the object being tested to paper, and in turn, securing the paper to the testing platform in the wind tunnel. Floral clay is a putty-like adhesive used by florists in elaborate floral arrangements. It is inexpensive and in securing an object to paper, was the most effective method found. 3M Spray Adhesive was found to be the best method of securing the paper to the test platform.

Objects

Objects had been limited to several steel cylinders and small gears found in the laboratory. Models of vehicles were used as well. The auto models were cut in half along their centerlines in order to visualize flow over their central axes. The model car inventory included a Jaguar Formula One race car, a BMW Z8 convertible, and an unspecified model of a Mercedes race car. The model cars were cut with a band saw.

Oil of Wintergreen

The oil of wintergreen was used, and the quality of the results was dramatic. One of the problems with oil of wintergreen, however, was its adverse effect on painted surfaces, particularly the test platform. Moreover, oil of wintergreen has a strong odor despite the small amount used: approximately 1/3 ounce per test run. The fragrance remained for over 24 hours.

FINAL SOLUTION

After many trials, it was decided to use a blue Sharpie® markers, some glossy photo paper, and straight isopropyl alcohol. Beautiful, clear streak lines, with little or no bleeding, came from a combination of readily available, low-cost materials.

LABORATORY INSTRUCTIONS TO STUDENTS

The reason for conducting this study was to develop a low cost, effective procedure in the fluid mechanics laboratory for obtaining streamlines of flow past an immersed body. This experiment will complement the corresponding lecture in the course. A procedure for conducting this experiment is provided to the students, and that information now follows.

Materials Required

- isopropyl rubbing alcohol
- 1-2 sheets Glossy Photo Paper
- 1 household spray bottle
- 1 fine tip blue Sharpie® brand permanent marker
- 1 ball point pen (may substitute pencil, or other non alcohol soluble ink)
- Floral clay
- 1 test object to obstruct air flow (recommended to have a flat surface to affix to test surface)
- 3M brand spray adhesive
- 1 Removable, raised, test surface (optional, can be removed to allow 360 degree application of solvent before introduction into wind tunnel Figure 6)
- Funnel (optional, used to fill spray bottle with solvent)
- Scissors or razor (optional, for trimming photo paper to desired size)

Procedure

It is recommended that enough isopropyl alcohol be purchased to allow for the use of up to 0.5 fluid ounces per test. Mix isopropyl alcohol and water; put into the spray bottle and set aside.

The photo paper may be trimmed to fit the road or area of interest. A trace of the outline of the object should be applied to the photo paper using a ball point pen, or other non alcohol soluble ink or pencil.

Dots should then be applied to the photo paper roughly ¼ inch apart. These dots may be offset from one another, or placed only in areas of interest.

Each dot should be formed by a single firm press of the fine tip marker; each one should have a diameter of roughly 2-3mm. A stencil may be used to ensure consistent and speedy dot placement. (See Figure 2.)

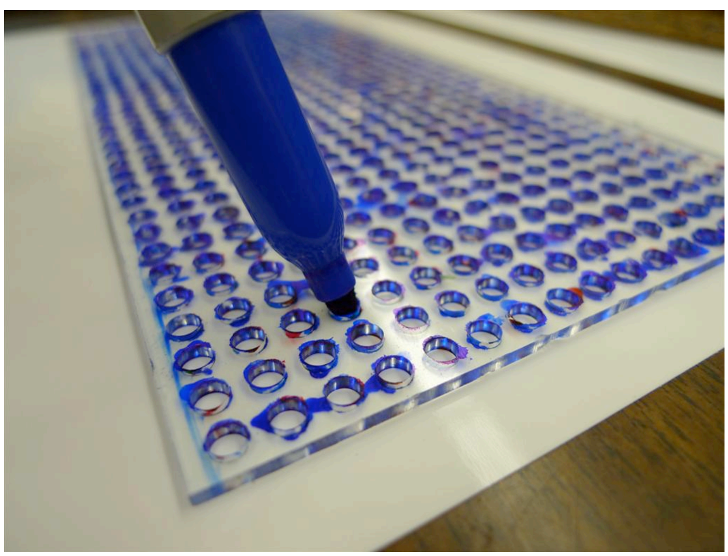

FIGURE 2 *Stencil used to apply ink dot matrix to photo paper.*

Affix the prepared photo paper to the surface where the model will be placed, using a very light spray of 3M adhesive. Apply a very light coating of the adhesive to the back of the photo paper, wait 30 seconds, then apply the photo paper (adhesive side down) to the test surface, ensuring that it is centered

The object of interest should be affixed to the surface of the photo paper using a small amount of floral clay. The object should be pressed down with enough force eliminate any gap from between it and the photo paper. If it is impossible to eliminate the gap, it may be filled in with a small amount of floral clay shaped to follow the outline of the object. The floral clay must have the strength required to balance the force exerted by the air flow on the object or interest.

The area above the assembly is sprayed with alcohol, allowing the alcohol to fall onto the dots on the photo paper rather than spraying the dots directly. Otherwise, the force of the sprayed droplets will cause the dots to run prematurely. Once all of the dots have been thoroughly coated with alcohol, the assembly should be carefully placed in the wind tunnel, keeping the photo paper as horizontal as possible to prevent the dots from running due to gravity.

Turn on the wind tunnel to a speed of 50-70 mph for optimum test results. A manometer or other form of pressure measurement is needed to determine the air velocity.

FIGURE 3 *Wind Tunnel and objects used.*

A lapsed time of 30 to 45 seconds should not be exceeded during the prep time; otherwise the solvent will dry before the wind tunnel is brought up to speed.

Allow the streamlines to fully develop; that is, they should settle into a pattern and cease significant movement. The ink should be dry (or nearly so) at this point. Once the alcohol is all evaporated, the assembly can be removed from the wind tunnel. Photographs should now be taken. Separate the object, photo paper, and bed

Proper lab cleanup procedure should be observed upon completion of each test or series of tests.

STREAMLINES OBTAINED BY UNDERGRADUATE STUDENTS IN THE FLUID MECHANICS LABORATORY

Following are photographs of layouts and of streamlines of flow obtained by students. Figure 4 is of a BMW Z8 24:1 model cut in half and mounted on a dotted piece of photo paper in the wind tunnel. The paper is sprayed with alcohol, and the fan is turned on. Results are shown on the right.

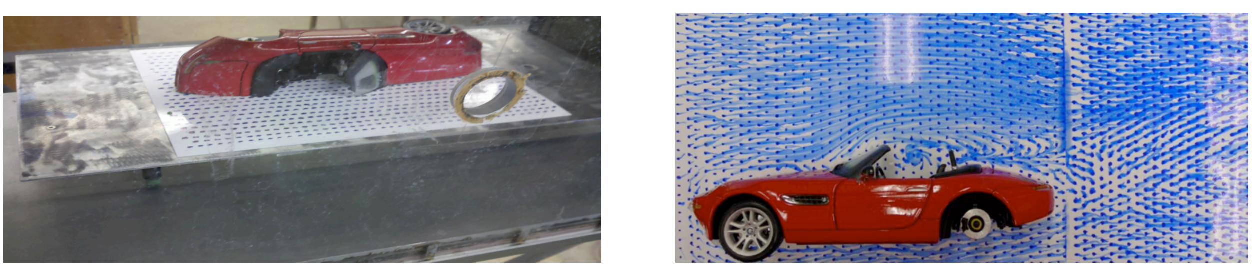

FIGURE 4 *Model BMW Z8 on prepared test sheet both attached to raised "road."*

Figure 5 shows the streamlines of flow about a circular cylinder. Although interesting to the career academician, this photograph and many others like it are available on the internet.

Far more popular with the students is flow past a vehicle. Figure 6 shows a 24:1 model of a Formula 1 race car. Streamlines were obtained in top and in profile views.

Figure 7 shows flow about a stock car modified for racing. Again the model size is 24:1, as this size is available commercially, and models are inexpensive. Virtually any vehicle can be obtained.

Note that the profile views of all vehicles shown involve cutting the vehicles in half.

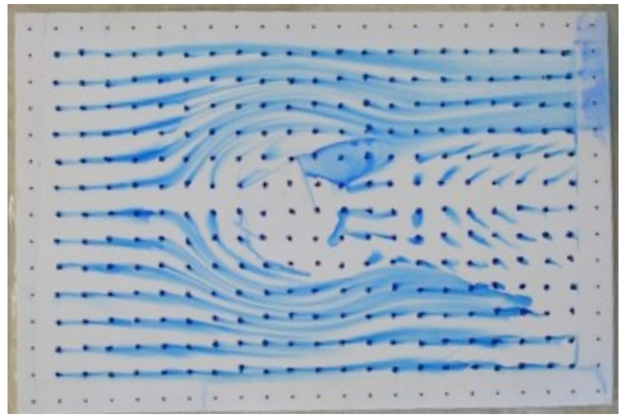

FIGURE 5 *Flow past a cylinder*

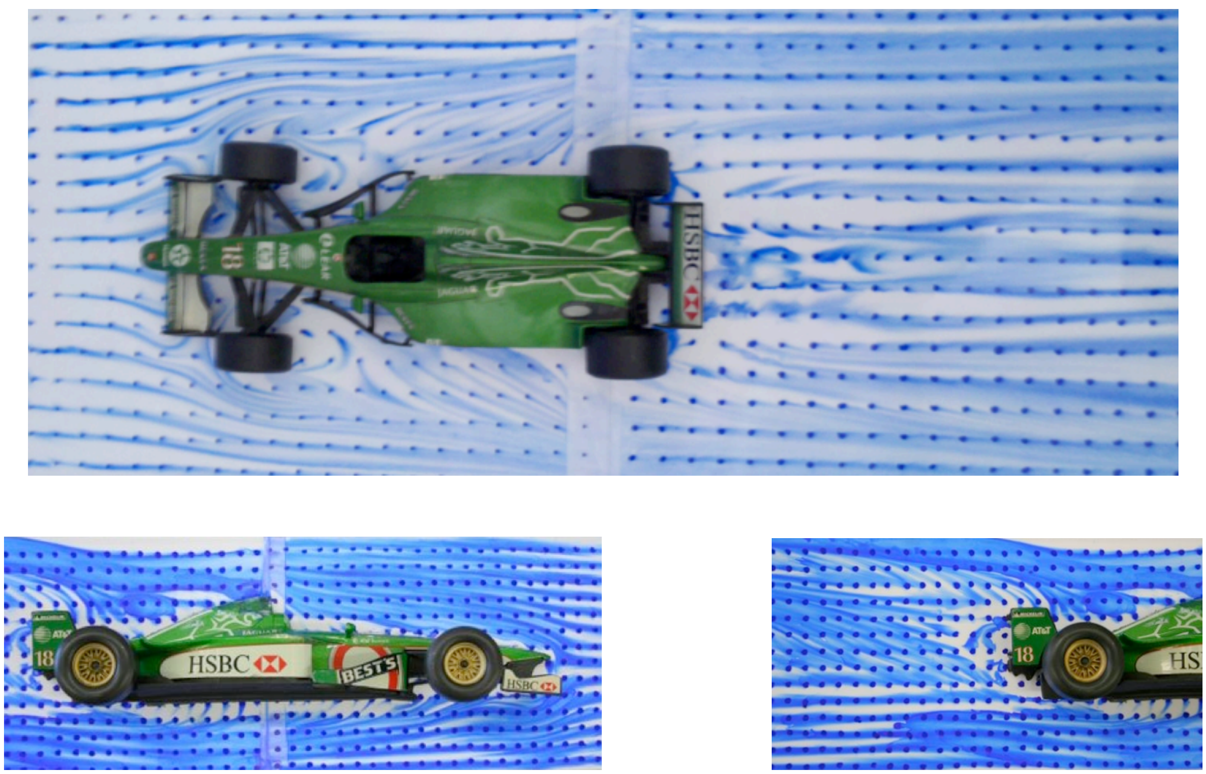

FIGURE 6 *Streamlines of flow about a race car.*

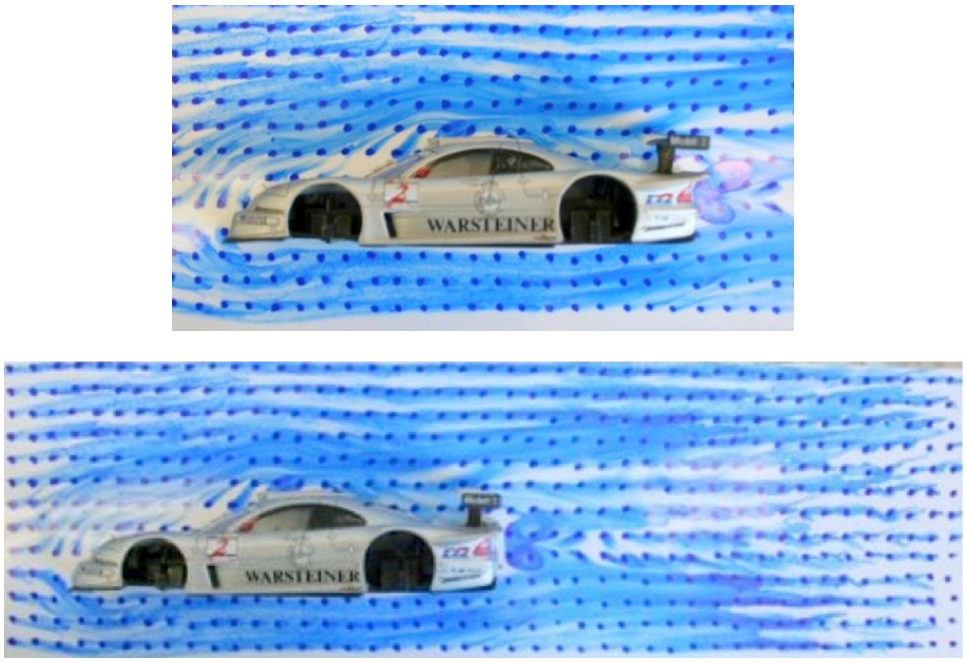

FIGURE 8 *Streamlines of flow about a stock car.*

CONCLUSIONS

The search for a simple and inexpensive method of obtaining streamlines yielded positive results. The ink dot method was modified appropriately for this study. Rather than oil of wintergreen, rubbing alcohol (diluted with water) is used. Inexpensive markers (available at a bookstore) and photo paper both are also used. The results shown here were obtained by students without the need for immediate supervision. It is concluded that the ink dot method of obtaining streamlines of flow is an effective technique that students can use to obtain rather interesting results. It is a welcome addition to the fluid mechanics laboratory.

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BIOGRAPHICAL INFORMATION

William S. Janna joined the faculty of The University of Memphis in 1987 as Chair of the Department of Mechanical Engineering. He served as Associate Dean for Graduate Studies and Research in the Herff College of Engineering. His research interests include boundary layer methods of solution for various engineering problems, and modeling the sublimation of paradichlorobenzene objects of various shapes. He is the author of three texts: a textbook in fluid mechanics, in heat transfer, and in design of fluid thermal systems. He has taught continuing education courses in the area of piping systems and in heat exchanger design and selection, for ASME. Dr. Janna received a B.S. degree, an M.S.M.E. and a Ph.D. from the University of Toledo.