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Images of Fluid Flow: Art and Physics by Students

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Abstract : In Spring 2003, a new experimental course on flow visualization was offered to a mixed class of Fine Arts Photography and Engineering students. Course content included fluid flow physics, history of photography with respect to the relationship of science and art, as well as flow visualization and photography techniques. Issues such as "What makes an image art? What makes an image scientific?" were addressed. The class focused on studio/laboratory experiences for mixed teams of students. In Spring 2004 these concepts were distilled into an engineering outreach experience for middle school girls. The spectacular images resulting from these experiments show that flow visualization can be both performed and appreciated by a broad spectrum of people. Thus flow visualization may represent a new bridge between scientists and non-scientists.

Keywords : Art, Science, Flow Visualization, Photography.

1. Introduction

The growing disconnect between engineers and the general public has been a topic for recent discussion and concern. On one side, we can work to educate the public about engineering, and on the other, we can educate our students to relate their studies to a greater world. Flow visualization has a unique appeal that makes it a candidate to bridge the gap between the cultures of those with a technological education and those without such background.

At the University of Colorado, Boulder, the authors (Hertzberg and Sweetman) won a small award to pilot a laboratory/studio course on "Flow Visualization: the Physics and Art of Fluid Flow," which was first taught in Spring 2003. Subsequently, some of the techniques that were developed in the course were applied to a single 45 minute outreach activity designed to expose middle-school girls to nontraditional careers, as part of the national "Expanding Your Horizons" program (middle school is when many girls decide against careers in science). One important goal of the course and the outreach experience was to expose students to an expression, an interpretation, of physics which cannot be accomplished verbally or mathematically, but only visually. Many fluid physicists are motivated not only by the important scientific and engineering goals of their work, but also by a visceral fascination with their subject. Few scientists or engineers publicly admit as such, but the existence of several venues for display of fluid flow art belies purely dispassionate motivations. Foremost among these venues is the Gallery of Fluid Motion, a poster and video competition which is held in conjunction with the American Physical Society Division of Fluid Dynamics (APS-DFD) annual fall meeting. Gallery entries are judged "based upon criteria of scientific merit, originality,

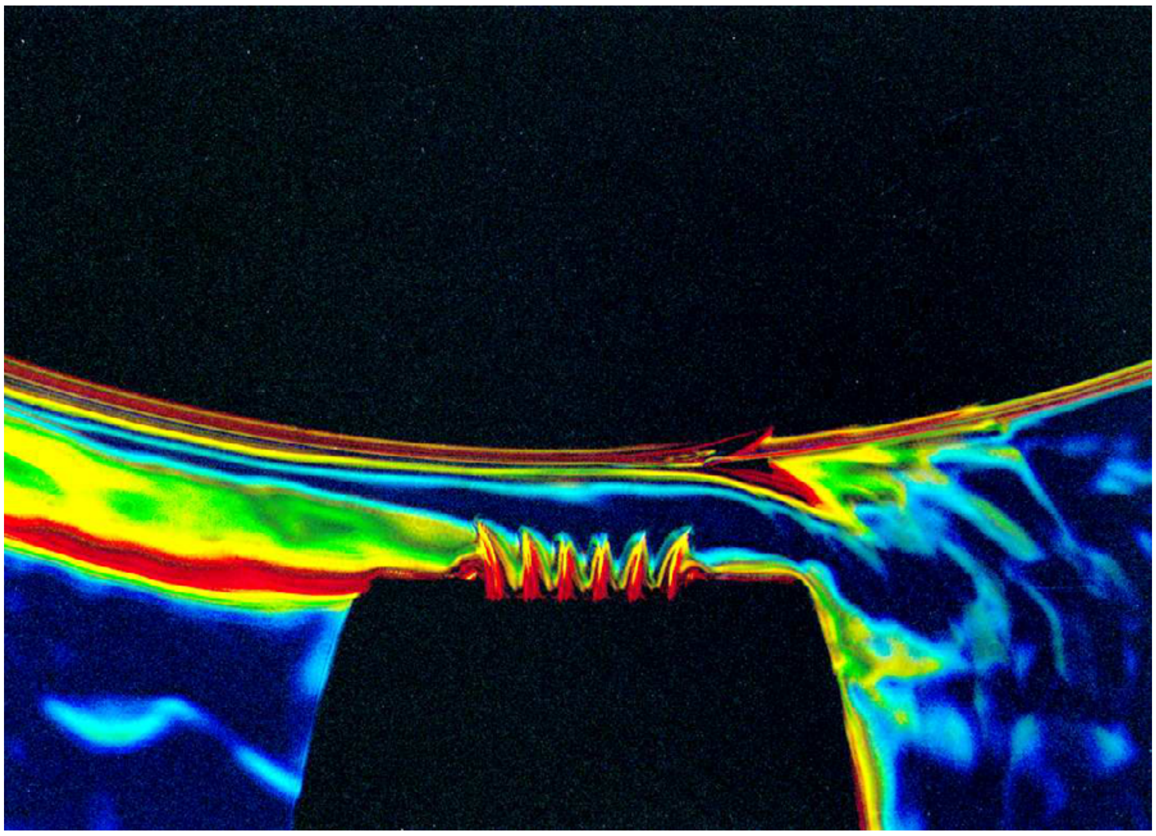

Fig. 1. Color schlieren image of flames impinging on a rotating drum. Colleen Stroud, by permission.

Fig. 2. Laser induced fluorescence of buoyant rhodamine plume impinging on free water surface. Sarah Stapleton, by permission.

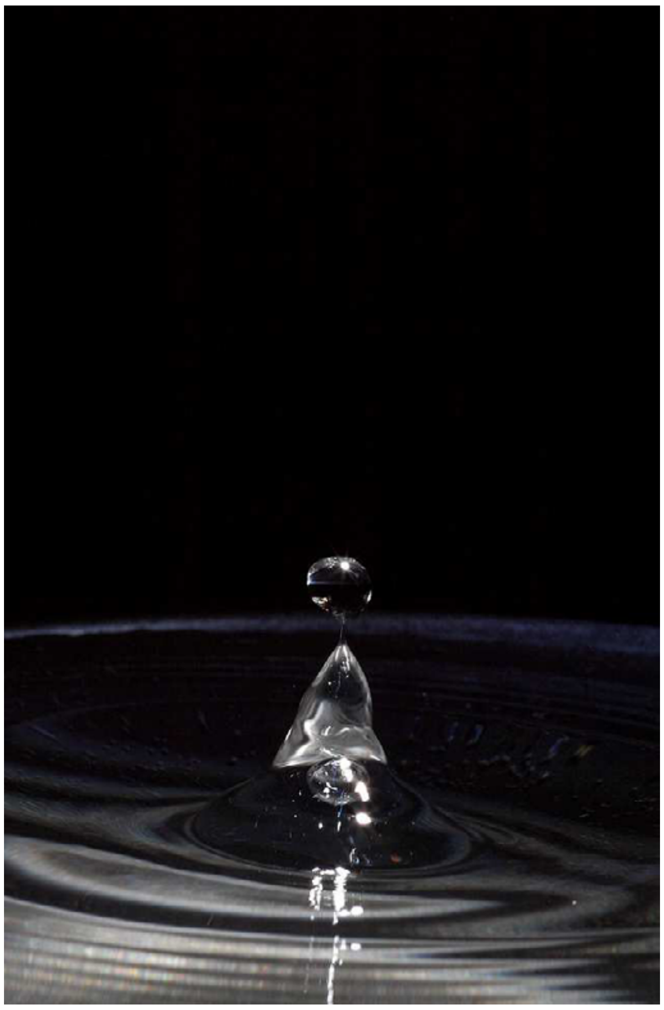

Fig. 3. Strobe image of a Worthington jet after the impact of a water droplet. Mark Donohue, Luciano Mazzaro, Blake Nolan, Tait Stangl, by permission.

and artistry/aesthetic appeal." Winners are published online (http://pof.aip.org/pof/gallery/index.jsp) and in a peer-reviewed journal, *Physics of Fluids,* and winners for the past 17 years have been recently collected into a volume (Saminy et al., 2003). A recent New York Times article (Schecter, 2003) about the Gallery attests to the potential for general impact on students and the public. Additional examples include the seminal *Album of Fluid Motion* (Van Dyke, 1982), which can be found on the bookshelf of nearly every fluid dynamics researcher, and the recent *Multi-Media Fluid Mechanics CD-ROM* (Homsy et al., 2000). In each of these examples, the sheer beauty of fluid flow is revealed and acknowledged to some extent. Thus we hope to encourage engineering students to gain a deeper perception of fluid flow by capitalizing on this previously unacknowledged motivation, that is, for aesthetic and creative purposes. In the case of the art students, and in the outreach experience, the goal was to introduce students to the simple beauty and fascination of fluid flow. Not all students will continue in their study of fluids, but may instead become more open to an aesthetic appreciation of, and motivation for, other fields of science and engineering.

2. Course Structure

Details of the course structure and content are described in Hertzberg and Sweetman (2004). Briefly, the flow visualization course was offered in Spring 2003 to a group of mixed engineering and fine arts photography majors. Of 42 students approximately 1/3 were fine arts students and 2/3 engineers.

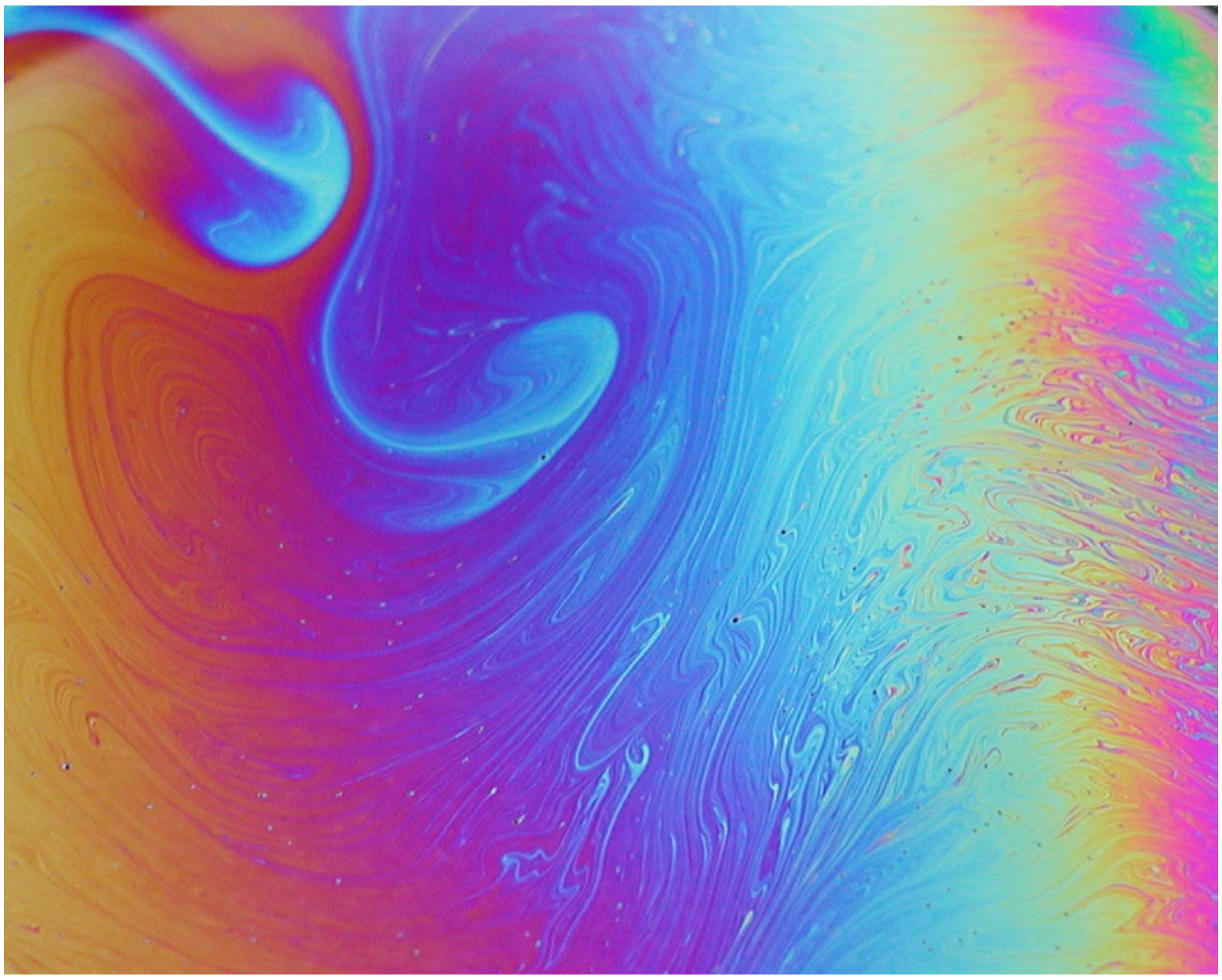

Fig. 4. Draining of a soap film, illuminated by diffuse sunlight. Jenelle Charbonneau, by permission.

Of the engineers, 40% were graduate students, and the rest were seniors. These ratios were predetermined by enrollment limits. The course was offered as a technical elective to the engineering students, and as studio credit to the fine arts students. Students were put on mixed teams of 3-5 students, chosen by the instructors to distribute technical strength in engineering and photography throughout the groups. The team approach worked well in most cases, allowing a couple of students to focus on producing the flow and visualization techniques, and the rest to focus on the photographic elements. Roles were then traded. Both engineering and art students reported positively on the interaction with students from the other discipline. The team approach had other benefits as well. Several of the graduate students were research assistants on projects with flow visualization equipment which was made available to their teammates. Art students provided image processing skills and made sophisticated photographic equipment available to their teams, although there was still a pressing need for digital cameras and printers. Digital photography was favored by the engineering students for the relatively low cost of processing, while most of the photography students had invested expertise and equipment in film.

3. Results

Despite the disparate backgrounds of the students enrolled in the course, no general differences in either the scientific or artistic quality of their images could be detected. The ranges of techniques, equipment and fluid phenomena were quite broad, from sophisticated visualizations of industrially

Fig. 5. Propane torch impinging on an orange. Dustin Grace, Marilyn Poon, Robert Neilson, Jessica Todd, by permission.

important flows to simple photographs of clouds, and were implemented by the full spectrum of students. At the traditional end of the scale, engineering graduate students used sophisticated imaging techniques on flows related to their research. For example, Fig. 1, by Colleen Stroud (2004) features the topic of her Ph.D. research. In this color schlieren image, methane/air flames are seen as small vertical elements at the center of the image. The flames impinge on a 25 cm diameter cylinder 10 mm above, which is rotating to the left at 5.5 meters/sec. The cool fluid being dragged with the cylinder conflicts with the hot flame gases. This configuration is important in the flame treatment of plastic films to allow printing on the plastic. The schlieren system used 12 inch diameter, 8 ft focal length mirrors. The schlieren stop was a transparency with concentric, discrete bands of color ranging from indigo in the center through green and yellow to red at the extremes.

Figure 2 shows laser induced fluorescence (LIF) of a 0.25 cm diameter buoyant rhodamine plume impinging on a free water surface 0.5 m above. The plume was excited by a 0.5 W argon ion laser beam swept into a sheet (Crimaldi and Knight, 2005). This image was created by another engineering graduate student, Sarah Stapleton, whose research position focused on implementing the LIF and flume system. Classic flow phenomena were explored using modern equipment, as shown in Fig. 3. This image of a Worthington jet, formed after the impact of a water droplet on a free surface, was made by one of the teams with both engineering and art students. One of the art students, Tait Stangl, provided a professional quality digital camera and strobe for the team.

However, many of the engineering students (and all of the art students) had no previous experience with the flows they generated. One of the engineering graduate students came across mention of the Saffman-Taylor instability in a text, and proceeded to put together a simple Hele Shaw cell to investigate it. The resulting image was selected for publication in the Gallery of Fluid Motion (Poon et al., 2004).

Fig. 6. Soap bubble made fluorescent with highlighter pen ink. Blake Nolan and Cody Haskell, by permission.

Fig. 7. Vortex ring in air, visualized with stage smoke. Emrys Hall, Thomas King, Bethany Rotherham, Brynne Sutton, by permission.

Fig. 8. Clouds over Canyonlands National Park. Bethany Rotherham, by permission.

Many of the flows investigated required little fluid flow apparatus as such, and only basic photographic equipment. Figure 4 shows a soap film formed in a jar lid, approximately 7 cm in diameter, illuminated by diffuse sunlight, and photographed with a point-and-shoot digital camera. Figure 5 shows a propane torch impinging on an orange. This image resulted from a desire on the part of the students to visualize a combusting flow, and reveals a wealth of interesting physics, including ablation, black body radiation, and the combustion of fuel-rich orange oil jets in cross flow. Figure 6 reflects the students' fascination with fluorescence; highlighter dye was soaked out of a pen, mixed with a soap solution to form bubbles and excited with a UV light. One of the art students on this team, Blake Nolan, has continued to explore this technique, and has made it a focus of his professional photography career (www.bjnart.com). Figure 7 shows a vortex ring visualized by filling a 1.5 m^3 cardboard box with theatrical fog. The vortex ring was ejected from a 12 cm diameter hole in the box by tapping the outside of the box firmly. A slide projector provided illumination. The left image was mirrored and reversed digitally.

At the far end of the equipment scale from the research flows, students were assigned to photograph atmospheric fluid dynamics as revealed by clouds. The upper quarter of Fig. 8 shows a mid or high level stable wave structure, with parallel bands of clouds stretching from the upper left towards the lower right of the image, while lower cumulus clouds seen in the central third of the sky portion are the result of uneven heating of the earth combined with an unstable lower atmosphere.

Several of the setups requiring minimal equipment were used again later in the outreach experience for middle-school girls. Several basic fluid flow concepts were illustrated: jets, boundary and shear layers, laminar vs. turbulent flow, mixing, buoyancy and vorticity. Girls created negatively buoyant jets using diluted food coloring ejected from syringes into a 10 gallon aquarium tank, while positively buoyant jets were created using isopropyl alcohol dyed with food coloring, injected into small transparent food containers with flat sides, filled with a stratified layer of water above corn syrup. Vortex rings in air were visualized as in Fig. 7. Smaller vortex fog rings were also generated using a Zeroblaster (www.zerotoys.com), a commercially available toy. Only one experiment required significant equipment. A 2.5m x 76mm x 250 mm open channel flume was to generate boundary layers, free shear layers and laminar and turbulent mixing flows, which were visualized with food coloring dye.

Students created a wide range of innovative flows and techniques during the semester. Additional techniques and flows explored by students over the course of the semester included immiscible fluid interfaces which displayed Marangoni effects, free surface waves, free and impinging smoke plumes, and time exposures of flexible strings in turbulent flow. A selection of images from the course is available on the course website (www.colorado.edu/MCEN/flowvis).

4. Conclusion

The results from this experimental course illustrate very clearly that flow visualization can be performed successfully by a wide range of people, with a wide range of equipment that extends from experts with the most sophisticated visualization techniques to a child with a $10 camera looking up at the sky. The engineering students made beautiful images, and the art students made accurate observations of interesting fluid phenomena. While an understanding of fluid physics, and of art can each contribute to images with impact and utility, extensive training in these areas is not a prerequisite. The appeal of flow visualization seems to be universal.

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Author Profile

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Alex Sweetman: He is a Professor of Art and Art History at CU Boulder. His B.A. is from New York University, Washington Square College, and M.F.A. is from the SUNY Buffalo, Program in Photographic Studies, Visual Studies Workshop. His creative work is in the area of studio photography, with over one hundred exhibitions, and more than thirty solo exhibitions. His research is in visual studies, especially the history and theory of visual media.