

Aesthetics of Flow Visualization

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Introduction

The terms 'art' and 'science' have been linked ever since the advent of the university system in medieval times. Originally they were closely related; in Greek and Latin the meaning of 'art' encompassed all human activities, including fine arts, crafts and sciences. Since then, the fields have grown far apart. In the 18th century in Western culture, the concept of 'fine arts' was invented, and crafts and engineering were relegated to 'applied arts'[1]. Soon after, as the advent of photography freed visual art from its duty to record accurately, emotion became more prized in fine arts with the development of Expressionism, while objectivity came to be more and more prized in science. Today, 'art' is used to refer to primarily fine art, created for aesthetic purposes. The STEM disciplines, in contrast, are ever more dedicated to solving all manner of problems. Is there any helpful relationship between the two? Is there any cost to divorcing them?

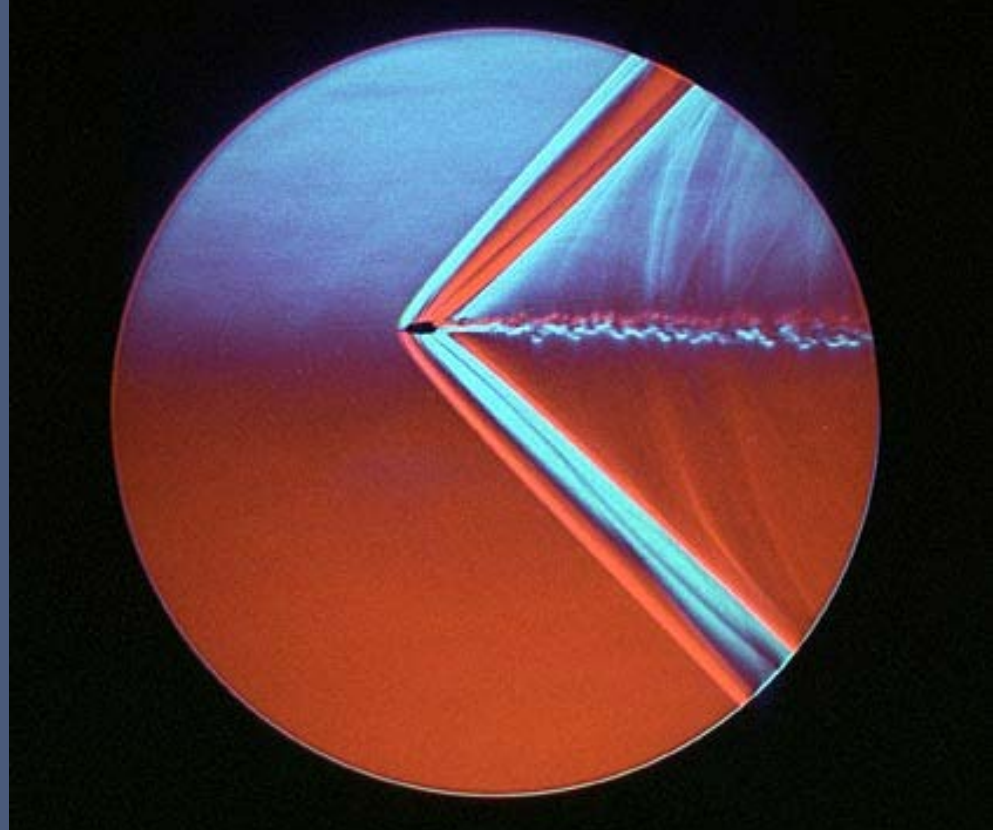
The field of aesthetics may provide a useful bridge. Aesthetics is often defined as the philosophy or study of beauty, and can thus be used as a metric of art. One can apply an aesthetic to determine if a particular artifact is, in fact, art and rate it good or bad. However, aesthetics can also be separated from the concept of art. Palmer et al[2], in their psychology-based review of visual aesthetics, define *'aesthetics to be the study of those mental processes that underlie disinterested evaluative experiences that are anchored at the positive end by feelings that would accompany verbal expressions such as "Oh wow! That's wonderful! I love it!" and at the negative end by "Oh yuck! That's awful! I hate it!"'*. Such a definition easily can be extended from responses to visual stimuli to responses to other stimuli such as physics education, or any art, in the original sense of the word. This behavioral definition of aesthetics is closely related to Dewey's[3]. When we are interested in a student's affective response to physics topics and the activities of science, perhaps we can use aesthetics as a type of framing. However, in contrast to the aesthetics of visual art, where there is a large interrelated body of work linking human affective response and perception to the form, content and philosophy of visual art, the aesthetics of physics are relatively unexplored.

Flow visualization (flow vis) is one example of a topic that closely couples physics and aesthetics. At the University of Colorado, MCEN 4151/5151 / Film 4200 / Arts 5200: Flow Visualization [4] is a technical/studio elective offered to both graduate and undergraduate engineering, photography and film majors. Students work in mixed teams, but all students are expected to both exert conceptual control as artists, and document accurately as scientists. Flow vis can be used as an aesthetic bridge between art and science beyond the formal classroom as well. FYFD [5] is a surprisingly popular blog about fluid physics on Tumblr, and the Flow Visualization Facebook group [6] is continually growing. Flow visualization can contribute strong messages of science content within the community of physics and fluid mechanics researchers, but when communicating outside this community it is the aesthetics of fluid flows that carries the greatest weight.

The aesthetics of flow visualization can be grouped into four categories: beauty, power, destruction and oddness. These categories are currently based on anecdotal observation of the predominant choices certain populations make when given the opportunity to share examples of visual representations of fluids, and are thus assumed to engender positive affect and meet with aesthetic approval. These populations include students in the Flow Visualization course, other undergraduate mechanical engineering students at CU Boulder, and members of the open Facebook group 'Flow Visualization'.

Power

The aesthetics of power are all about control; control over fluid physics, over money, and over other humans. This aesthetic is prominent in images of aerospace technology such as fighter aircraft and rockets, and in images of controlled extreme flow conditions such as shock waves and high Reynolds number fluid jets.



Above: Supersonic bullet and shock wave Andrew Davidhazy, <http://www.4000.org/2013/03/10/supersonic-bullet-and-shock-wave/>
Left: The Space Shuttle Endeavour lights up the night sky as it embarks on the first U.S. mission dedicated to the assembly of the International Space Station. National Aeronautics and Space Administration, 12/04/1998. Photo KSC-98PC-1788. <http://mediaarchive.ksc.nasa.gov/detail.cfm?mediaid=2710>



FA-18 Hornet breaking sound barrier. U.S. Navy photo by Ensign John Gay, 1999. Temperature drops in the expansion wave behind the attached shock, resulting in condensation. <http://www.news.navy.mil/management/photodb/photos/990707-N-6483G-001.jpg>

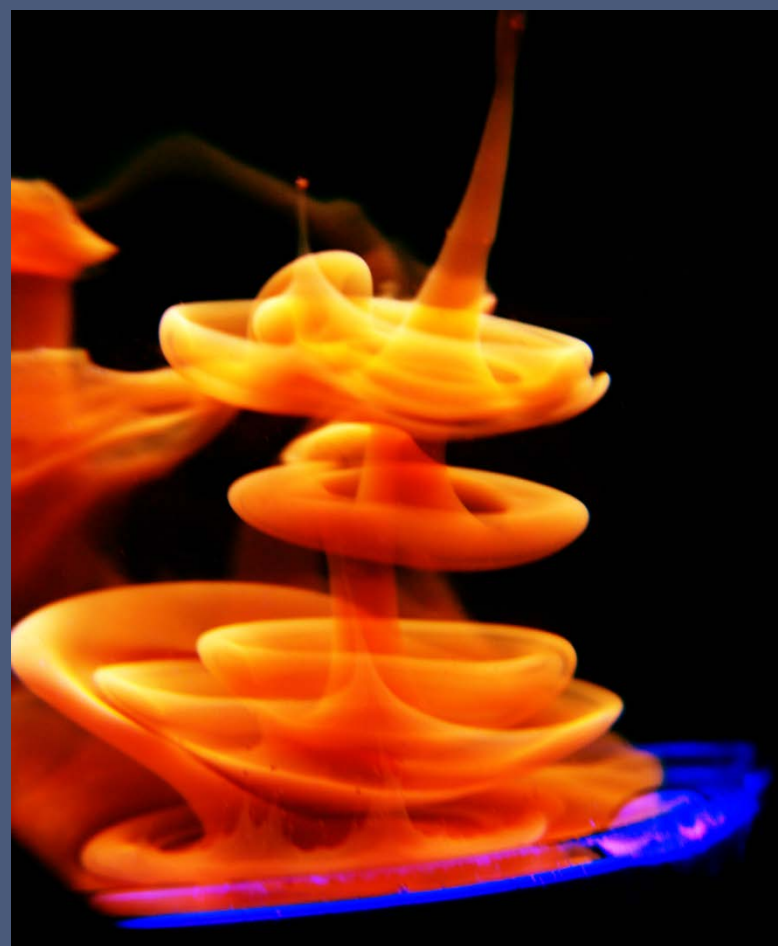
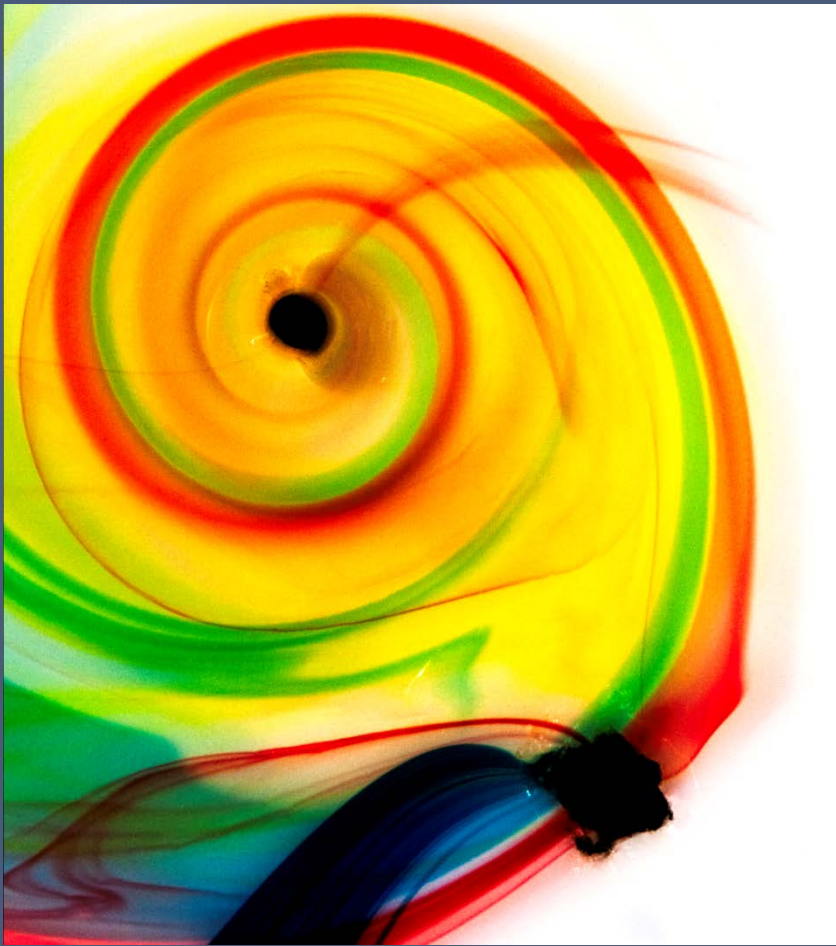
Beauty



Turbulent flow in a flume around an obstacle, visualized with dye, and color-reversed. Kyle Manhart, Gregory Kana, Jared Hansford, Matthew Campbell, Andrew Scholbrock, 2011.



Above: Saffman-Taylor instability in a Hele-Shaw cell: dyed water injected into honey. Travis Ochsen, Grant Meaux, Shane Weigel 2011
Right: Only one 'bathtub vortex' formed in a bucket with two holes in the bottom, viewed from the top with food dye. Jonathan Varkovitzky, Chris Svedman, Peter Mitrano, 2010.
Far right: Dyed mineral oil, illuminated in the UV, forms vortex rings upon injection by syringe. Jacob Varhus, 2013.



Aesthetics is sometimes defined as the study of beauty. This is the most well known aesthetic in Western culture, and dates back to Plato at a minimum. The use of fluid dynamics in works of art measured on this scale also date back to the origins of human art, in representations of the sea and clouds. More recently a number of professional artists have been exploring the beauty of fluids in both abstract and representational forms; images and videos of splashes, laminar smoke plumes and breaking shore waves are common.

Destruction

The aesthetics of destruction represent an inverse to the aesthetics of power. Destruction represents a total loss of control, of order. Representations of explosions, wildfires, thunderstorms, tornadoes, tsunamis, and avalanches (a type of granular flow) typify this aesthetic. For example, large scale fluid dynamics such as storms, tornadoes, floods and wildfires are often responsible for massive destruction, yet humans draw pleasure from watching such destruction from a safe distance. Can this voyeurism be turned to our advantage in communicating science?

Below: Fire artist Nate Smith (<http://www.flamingotornado.com/>) injects liquid propane into a 25 foot diameter flaming vortex, generated by a ring of fans, at the 2007 APS Division of Fluid Dynamics annual meeting. The flaming tornado reached 76 feet in height. Photo by Jean Hertzberg.



Oddness

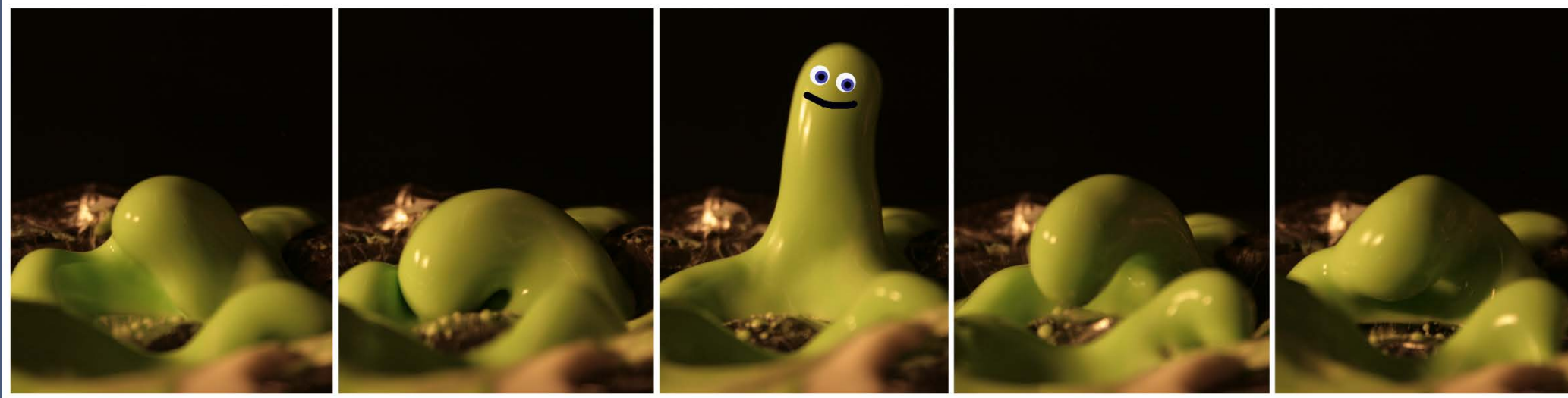
Humans have an intuitive understanding of fluid physics. After all, we are basically bags of water, and spending our lives submerged in an ocean of air. Thus, unexpected fluid physics elicit an intense fascination. Non-Newtonian fluid behaviors and high speed photography of fluids are particularly popular.



Above: Shampoo, a shear-thinning fluid, exhibits the Kaye effect when a stream impacts a surface. Streamers are ejected, and periodically interfere with the incoming stream. PasWink 2012. <http://www.flickr.com/photos/g2525759@No8/8456571967/n/photostream/>



Above right: Water Wigs is a dynamic set of images using exploding shaped water balloons lit with a triad of colors, to create incredible splashes on the heads of bald men. The result is interesting and arresting "wigs" of water. Tim Tadder, 2012. <http://www.behance.net/gallery/Water-Wigs/4889175>
Below: Oobleck is a colloidal suspension of cornstarch in water, and behaves as a dilatant, or shear-thickening fluid. Here oobleck is placed on a loudspeaker and vibrated. The resulting motion has the appearance of strange life. Matthew Phee, Austin Edwards, Andrew Bornstein, Tyler Coffey, Steven Hendricks, 2011.



Context and Future Work

This exploration of fluid aesthetics is part of a study, "The Power of Aesthetics". Flow visualization is the process of making the physics of fluid flows (gases, liquids) visible, and is well-established as a research tool in the field of fluid mechanics. Beginning in 2003, a course on flow visualization (FV) has been offered to mixed teams of engineering and fine arts photography graduate and undergraduate students at the University of Colorado. The course has significant technical content on flow visualization and photographic techniques, and includes some emphasis on documentation and the interpretation of results, particularly with respect to atmospheric dynamics as revealed by clouds. What makes this course unusual is the emphasis on the production of images for aesthetic purposes: for art. Preliminary data suggest that this course has a positive impact on students' perception of and attitude towards fluid physics, which can be contrasted to the effect of traditional introductory fluids courses.

This evidence raises research questions in two areas: 1) what is changing in students' perception? Are they acquiring visual expertise? 2) Is this effect significant with respect educational outcomes such as recruitment and retention in school and the workforce, cognitive gains and 'life-long learning'? These can be synthesized into an over-arching research question, "how does increasing visual perception of engineering topics improve educational outcomes?" This question is quite broad, and must be broken down into more focused questions that can be answered using established cognitive science and education research techniques. For example: 1) does a FV experience increase visual expertise? How much and what type is needed? 2) Does increased visual expertise impact educational outcomes? 3) Does FV improve student attitudes and emotions (affect) about fluid mechanics? If so, why? Is it related to the pedagogical techniques employed in the course, or to the emphasis on aesthetics? Does this improved affect result in better outcomes? 4) What aspect of increased visual perception has the most impact on educational outcomes? Specifically, does aesthetics give FV its power? Is it the creativity required to make images? The classroom community including art students? Or is it love of physics?

These questions involve issues in a wide range of interrelated subfields within cognitive science such as creativity and aesthetics, perceptual expertise, educational outcomes, affect and motivation, and their overlap with course content and pedagogy related to photography, fluid mechanics and flow visualization.

Activities to be conducted will include two focused tasks: 1) a mixed-methods attitude study of students in the FV, Perception of Design and Fluid Mechanics courses, as well as in a control course, an upper-division technical elective on Sustainable Energy. Preliminary results from a partially-developed survey show that the FV students, who made images for aesthetic purposes, felt more strongly at the end of the course that fluids were useful to themselves and society, while the Fluid Mechanics students who spent an entire semester solving relevant engineering problems in fluid mechanics emerged feeling fluids was less useful than when they began. We will also study the development of students' use of representation and meta-representational skills. 2) Conduct a preliminary perceptual training study to examine whether a short flow visualization experience can produce visual expertise akin to that of bird watchers, for example. The study will involve sequential matching tasks and training in recognition of fluid physics. For example, students may be shown images of superficially similar flows such as a vortex and a breaking wave, and be asked to identify the relevant physics.

Acknowledgements

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References

- Unless otherwise noted, these images are drawn from student work for the Flow Visualization course (MCEN 4151/Film 4200). Additional examples can be found on the web; for example a curated site collecting professional artists working with fluids as a medium can be found at <http://www.scoop.it/t/flow-visualization>, and an extensive collection of flow visualization images made for scientific purposes is available at <http://www.efluids.com/>.
- [1] P. O. Kristeller, "The Modern System of the Arts: A Study in the History of Aesthetics Part I," *J. Hist. Ideas*, vol. 12, no. 4, pp. 496–527, Oct. 1951.
[2] S. E. Palmer, K. B. Schloss, and J. Sammartino, "Visual aesthetics and human preference," *Annu. Rev. Psychol.*, vol. 64, pp. 77–107, Jan. 2013.
[3] J. Dewey, *Art as Experience*. Perigee Trade, 1980.
[4] Flow Visualization course website: <http://www.colorado.edu/MCEN/flowvis/>
[5] <http://fuckyeahfluidynamics.tumblr.com/>
[6] Flow Visualization Facebook group: <https://www.facebook.com/groups/FlowVisualization/>