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HANDS-ON EXPERIMENTATION IN THE FLUID MECHANICS CLASSROOM AS HOMEWORK WITH EFLUIDS.COM

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ABSTRACT

In an introductory fluid mechanics course, it is important for students to realize that the mathematical models they are deriving in class sometimes model the real world well and sometimes not so well. One way to demonstrate this is to have the students model a simple experiment and compare the results of the model to those of the experiment. This exercise teaches the importance of the model assumptions and the applicability of the model. It would be even more effective if the experiments were simple enough so that students could do them at home as a homework assignment, rather than restricting their experience to a "canned" two hour lab course. At eFluids.com, we are building a library of such experiments in an effort to build a community of educators that moves beyond the traditional mathematical exercises for homework. Here, we describe a number of these experiments and how they can be used in classes. We also present some methods of using the eFluids.com Gallery of Images in the classroom to give students the opportunity to see "Fluids in Action". Finally, we introduce the eFluids Olympiad section where faculty can post effective and “interesting” homework problems.

INTRODUCTION

A traditional course in fluid mechanics places a heavy emphasis on the derivation and implementation of equations and formulas that are used to mathematically model and numerically predict physical phenomena. Such a math-based approach to modeling is important for a students’ understanding of the physical phenomena, but has a tendency to let the student lose sight of the true goal of the class: the explanation of observed behavior, which incorporates an in-depth physical understanding [2]. For example, to know the derivation of the Bernoulli equation is important, but a student must first be able to physically recognize a streamline and understand the basic tendencies of a flow to be able to apply it correctly; one must also understand when this simple relationship is inapplicable and resist the temptation to use it indiscriminately.

By incorporating simple experiments into the fluid mechanics curriculum, students can get an improved understanding for the physical meaning of the modeling they produce mathematically [3]. When required to predict the outcome of a simple experiment before it takes place, students are forced to apply their everyday experiences and knowledge to the subject at hand. These predictions, and therefore the experiments themselves, become meaningful and begin to take on significance beyond that of equations on the blackboard.

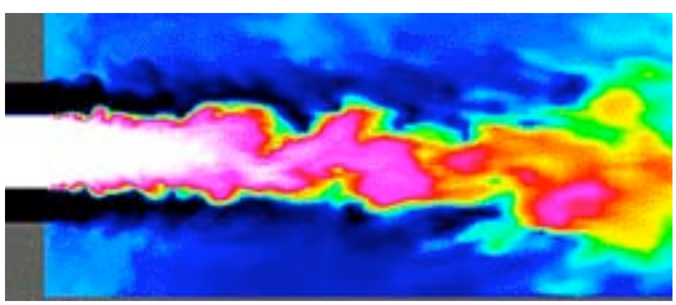

Figure 1: Turbulent flow simulation [1]

Some recent fluid mechanics textbooks have begun to take a more “physical” approach to teaching the subject. They describe and show still images of real life examples (for instance, the jet in Figure 1), and incorporate the con-cepts and principles in the examples into the text via multimedia disks [4]. However, one can only accomplish so much through writing, and it is the mathematical aspect of fluid mechanics that lends itself more to printed explanations. The physical aspect of fluid mechanics is more difficult to put into words and is probably best explained through experimentation. Though textbook explanations are better than no explanations at all, we believe that nothing can compare to experiencing the phenomenon first-hand. A formal laboratory experience can be very useful in this regard [5], but not every student has access to this experience, and, in any case, students should experience a wide range of fluid mechanics phenomena. A textbook could come with a bag of supplies and instructions for how to use them. Through these experiments, performed typically outside the classroom in a homework-style setting, students can see, for example, the intricacy and complexity of turbulent vortices being shed around a cylinder, or witness the pressure drop created by blowing air around a straw. As the Internet starts to play a larger role in engineering education [6,7], it seems that sites like www.eFluids.com could help through providing a collection of fluid mechanic images, experiments, and unique homework assignments.

CURRENT SET OF SAMPLE EXPERIMENTS

Currently, the eFluids.com website showcases 14 simple experiments that can be done either in the classroom or as a homework assignment by students in an introductory fluids course. eFluids.com is a specialty web portal designed to serve as a one-stop web information resource for anyone working in the areas of flow engineering, fluid mechanics research, education and directly related topics. It is designed to become the first step on the path to solving problems in flow engineering and fluid mechanics research and development for the global fluid dynamics community by providing engineers, industry professionals, researchers, educators, and students with a consolidated, intelligently selected and organized database linking all aspects of the fluid flow specialization. The experiments in the eFluids.com website have been chosen in order to be straightforward in set-up and most cost no more than a few dollars to build. Importantly, each experiment draws hands-on attention to at least one significant concept covered in the course. The website is designed so that the materials, goals, and processes are laid out for each experiment on a separate page, including a short video clip showing the experiment working. Experiments are divided into four categories: Dimensional Analysis, Static Flows, Inviscid Flows and Viscous Flows. We aim to significantly increase this number with time, and actively seek additional contributions from eFluids.com members.

For example, when studying the Bernoulli equation, students would be asked to predict the behavior of streams of water issuing from three different holes in a water bottle (see Figure 2). Once they have modeled the flow and estimated the three trajectories, they can then perform the experiment using a soda bottle, a pair of scissors, and a ruler. In this way, they can see how to apply Bernoulli's equation, and at the same time identify the limitations of the model. Part of the assignment could be to estimate the cause for the difference between the data and the model – in this case it is most likely frictional losses at the exit, the varying height of the water column in the bottle, and some additional effects due to the way the exit holes are cut. Alternatively, students can be asked to calculate the placement of the hole that will produce a jet of water to travel the furthest horizontally.

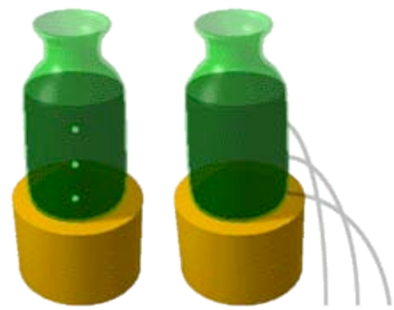

Figure 2: Online model showing experimental setup [1]

The model can be made more complicated by incorporating the steady lowering of the water level within the bottle as water exits through the holes. Once students have mastered modeling the basic system, frictional and head losses can be incorporated, and the improved models can be compared to the simple ones. They can also apply their equations to the system demonstrated in the video on the eFluids.com site. Dimensions and conditions are supplied so that the students can calculate the trajectories and compare their calculations to their observations in the film.

This problem can be considered in class as well as at home. The instructor can set the experiment up in front of the class and have students take measurements, possibly running several trials of the experiment if the class period permits. Then students can work alone or in small groups with the experimental data acquired as a class to determine the exit velocity of each stream or the water pressure at each exit hole, depending on what was asked of them. This allows for one on one attention from the instructor while other students are working, ensuring a better understanding of the concept. If the instructor feels that the class as a whole is not clear on a specific point or points, the class can reconvene to discuss them, with the intention that some students might be able to better explain it to their peers.

Other examples given on the eFluids.com website include experiments in statics such as the behavior of a liquid in a manometer and pressure differences due to depth. Students can make a basic manometer using vinyl tubing, filling it with water and then raising and lowering one end of the tubing while observing the relative liquid levels. They can then vary the pressure on either side of the manometer by placing a thumb over one end and repeating the procedure, again taking note of the relative levels of the liquid. By measuring the height difference, they can estimate the pressure differences on the two sides. Finally, they can add a less dense liquid, such as vegetable oil, to one side of the tubing, while keeping water on the other side, and observe the relative levels of both liquids, noticing that the two original liquid levels are no longer the same, though both ends are still open to atmospheric pressure. The experiment encourages students to try out different fluids of different densities and in different layer combinations. They can take measurements from their manometers, and determine the relative densities of each fluid, comparing them to values they can find in material property tables.

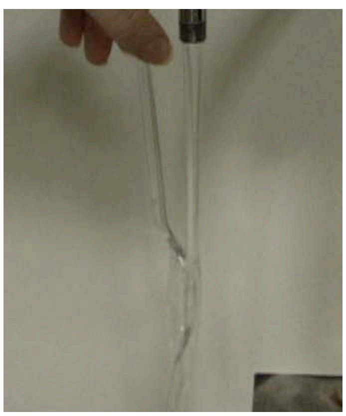

Figure 3: Still image taken from video of flow around a spoon [1]

In the inviscid flow section, students can experiment with the pressure drop caused by blowing air over the open end of a straw, and observe how it can be used to draw liquid up from the other end of the straw (similar to a paint spraying apparatus). If done in class, this experiment quickly teaches them that they can vaporize water and spray it at their classmates, adding some entertainment. Flow around curved objects such as ping-pong balls and spoons are also covered in this section. By loosely holding the curved end of a spoon under a laminar flow from a faucet, students can actually feel the force due to the streamline curvature as the water flowing around the spoon draws the spoon into the flow (see Figure 3). These experiments are more qualitative in tone, as modeling and quantitative measurements are, in this case, more difficult.

Interior and exterior viscous flows are also covered. For instance, the damping due to interior viscous flows is evident when students spin two eggs on a table, one hardboiled, the other raw, and notice the different rates at which each slows its spin. Due to the viscosity of the raw yolk and white, the raw egg will stop spinning much faster, and given the force with which each egg was spun, students can actually approximate the damping related to the interior flow, taking the hardboiled egg as having a solid interior.

All 14 experiments on the site include a materials list, specific goals and directions, a short video clip, and a brief discussion of the phenomenon evidenced by performing the experiment. The descriptions are easily manipulated into a printable format, so that access to the Internet is not required to perform the experiment.

By predicting, performing and mathematically modeling such experiments, it is our experience from the classroom that students get a better appreciation not only for the class material covered, but also for the scientific processes involved in creating a mathematical model. As part of our long term goal, we intend to use eFluids.com to help create a community of educators dedicated to sharing ways of bringing hands-on experimentation into the fluid mechanics classroom.

TEACHING THROUGH PICTURES

The website also has a gallery of images from hundreds of sources. These images are still pictures of various natural phenomena. In fluid mechanics, as elsewhere, a picture can be the difference between confusion and understanding. For instance, the difference between laminar and turbulent flows is much more easily explained by showing images than by stating values of Reynolds numbers. And though the growth of a boundary layer can be modeled mathematically, one understands its behavior and appearance from observing it in pictures and live flows. Students of fluid mechanics draw diagrams as part of their assignments, and some answers are entirely pictorial, so it is only fitting that they should be shown the real world images that their diagrams approximate. Flow lines and streamlines, for example, are often roughed out in sketches, but images of actual flows provide students with better qualitative explanations, and analysis of the images can also provide quantitative information.

The eFluids.com Gallery currently has over 100 images illustrating all aspects of fluid mechanics. They are freely available to help teachers show rather than tell. Students can also be motivated to browse the images if they are used as a discovery tool when set in terms of homework or other individual assignments. For example, students can be asked to list all images that show trailing vortices or to estimate a Reynolds number based on the scaling factors shown in the images. The image portion is currently divided into four Folios, each containing about 25 images. We are working on developing a better database mechanism based on major topic areas, similar to the one for the experiments, where a user can quickly and easily find, for instance, four pictures demonstrating the onset of turbulence. The pictures from the gallery come from researchers all over the world and sometimes include links back to individual websites for more information. We are continually soliciting new contributions from eFluids.com members and visitors.

OLYMPIAD OF FLUID MECHANICS

To further facilitate and stimulate the interest of undergraduate students in the field of fluid mechanics, we are developing an Olympiad of fluid mechanics. This competitive project will also serve to demonstrate the universal acceptance of fluid mechanical principles, encourage undergraduate students to browse through eFluids.com, offer an additional resource to fluid mechanics instructors and to promote international collaboration and understanding in the area of fluid mechanics instruction and learning.

In its first phase, the Olympiad will consist of a collection of original, self-contained, elementary problems, accessible through eFluids.com, appropriate for a first undergraduate engineering course in fluid mechanics. As much as possible, these problems would relate to natural phenomena, everyday life activities, history or technology, in order to demonstrate the practicality and diversity of the subject.

Like all other aspects of eFluids.com, the material will be available to any instructor or student of fluid mechanics no strings attached, except for respecting intellectual property rights. Typically, the instructor will assign as a required task one or more of the listed problems to his/her class. An effort should be made to introduce some interaction or competition among classes from different institutions. Problems will be presented in English, with expert translations in other languages to assist in technical vocabulary development. Cross-linking to experimental and numerical projects and other fluid mechanics websites will be provided on selected problems. Future extensions will include compilations of problems in specialized areas, such as aerodynamics, gas dynamics, fluid machinery etc.

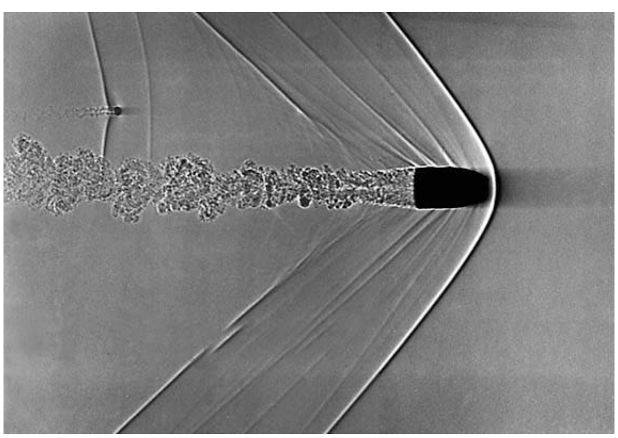

Figure 4: Flow around a supersonic bullet [1]

CONCLUSIONS AND FUTURE GOALS

Our goal is to make eFluids.com into the primary portal for fluid mechanics education, available free of charge to all users. To do this, we are building two galleries: one of experiments and one of images. We are also building a new Olympiad section to spark inter-university collaboration and competition on homework problems. The site is currently being updated to provide better access to the existing experiments, as well as incorporate the addition of new materials. We are in the process of adding simulation capabilities, so that students can simulate the experiments as well. By providing students with the numbers that accompany the experiments we exhibit, we can allow them to see if their models make “sense” of what they observed in the real world. For instance, by providing them with the bottle diameter, and the diameter and height of the holes in the water bottle fountain experiment, students can calculate the exit velocities and therefore distances traveled by each jet, as seen in the accompanying video. If we also provide the “answers,” the distances measured in the experiment, they can see how close their analytical answer came to the experimental one. Presently there are no means through which students can explore experiments that are more expensive to perform. We are currently submitting proposals to request funding for the development of this area of the website and the incorporation of numerical simulation techniques [8]. We are also looking to integrate the website with standard textbooks [9] in an effort to promote eFluids.com as a standard reference for teachers and students of fluid mechanics.

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