122nd ASEE Annual Conference & Exposition
June 14 - 17, 2015
Seattle, WA
Making Value for Society
Paper ID #11842

A Demo Every Day: Bringing Fluid Mechanics to Life

Dr. Laura A Garrison, York College of Pennsylvania

Dr. Laura Garrison received her B.S. in Mechanical Engineering from the University of Texas and her M.S. in Operations Research from Stanford University. She then worked for AT&T Bell Laboratories and AT&T Federal Systems before deciding to pursue her Ph.D. in Bioengineering at Penn State University in the area of experimental fluid mechanics associated with the artificial heart. After graduating, she worked at Voith Hydro for five years in the area of Computational Fluid Mechanics. For the last twelve years, she has been a professor at York College of Pennsylvania where she teaches thermal sciences, freshmen design courses, and computer programming.

Dr. Timothy J. Garrison, York College of Pennsylvania

Timothy Garrison is Coordinator of the Mechanical Engineering program at York College of Pennsylvania.

A Demo Every Day: Bringing Fluid Mechanics to Life

Abstract

Fluid Mechanics can seem particularly non-intuitive to the typical student. For example, most students will tell you that if velocity increases, the pressure also increases. Misconceptions such as these can be difficult for students to overcome. Multiple types of exposure to each topic, such as lecture, problem solving, and reading assignments can help, but demonstrations add another type of exposure that is not only informative and visual, but also enjoyable. Demonstrations during a lecture period can increase attentiveness and give the students a "feel" for the topic, helping them actually believe the concept that they are learning. These demos also provide an excellent memory point for the students to reference when they need to use the concept to solve a problem. Additionally, since both the instructor and student have experienced the demo together, the instructor can allude to the demo in order to help correct a misconception. By reminding the student of a demonstration, both student and professor have a starting point for discussion. This paper describes in detail over 30 demonstrations and videos that can be used to improve student understanding and to increase interest in the various topics associated with fluid mechanics. Demonstrations and videos have been developed for all of the topics covered in a typical fluid mechanics course including hydrostatics, viscosity, control volume analysis, similarity, Navier-Stokes solutions, pipe flow, minor losses, and external flow. Most of the demonstrations are inexpensive and were homemade by the authors and their students; most videos are readily available on YouTube.com. The paper reviews each of the demos/videos, discuss how they are incorporated into the class, and describe how to fabricate/procure the demo equipment.

1. Introduction

In the last few years, there has been an increasing trend in the debate about the pros and cons of active learning in the classroom, and many have moved away from the traditional lecture format.[1] While active learning comes in several forms, most agree that activities that are designed to engage the students, pique their interest, and are carefully selected to coordinate and supplement the lesson plans tend to improve students' understanding and retention of key concepts.[1] Although active or experiential learning has been highly promoted as of late, it has been researched for several decades. In the mid-1970s, David Kolb published works that categorized human learning styles and how they respond to various types of experiential learning.[2] At least three out of Kolb's four learning styles benefitted most through "concrete experience" and "active experimentation."[2] Furthermore, Schumann, *et. al*., reported that many students who leave engineering do so because of a lack of interest in the topics.[3] In 2010, in an effort to increase retention rates among engineering programs, the National Science Foundation sponsored a project called "Engage."[4] One of the three objectives of this project is to increase retention by "Integrating into coursework everyday examples in engineering (E3s)."[4] Also, a sampling of recent papers that studied the benefits of engineering classroom demonstrations all found positive results.[5, 6, 7] It is clear that hands-on activities and interesting demonstrations can improve student learning as well as increase retention in engineering programs.

Since topics in Fluid Mechanics can be seem quite abstract in students' minds, it seems to be a course that could especially benefit from the introduction of classroom demonstrations. Educators from several universities have posted lists of fluid mechanics demonstrations on-line, and some of these demonstrations have been used in the author's classroom.[8, 9, 10] The purpose of this paper is to present an entire semester's worth of demonstrations and videos, some from online sources and some newly created, with explanations of how they are used to pique the student's interest, to aid in understanding the topics, and to demonstrate results of an example problem.

Each year, the authors have added new demonstrations to the classroom. Last year, the instructor made a goal to bring a demonstration to every lecture. For every class that didn't already have a demo, an online search and/or brainstorming session was used to come up with ideas. Many of the demonstrations are not elaborate and are created out of items that are typically readily available. They are intended to give the students a feel for the topic and a memory for later reference. The authors hope that this paper not only inspires engineering instructors to use the demos, but to think of new ways to bring engineering to life. The authors plan to create a new website and post the ideas shown below or else to add them to other professor's websites, such as Nigel Kaye's excellent blog on this topic.[8]

One concern about adding demonstrations or videos to a lecture is the time it takes away from the presentation of new concepts. This paper's authors tend to use partially-flipped or fully-flipped classrooms which leave more time for demonstrations, but still do not want the demonstrations to take too much time that could otherwise be used for lecture or problem-solving. A majority of the demonstrations and videos listed below take three minutes or less. Two of the videos take the approximately 10 minutes each, and one worksheet with nine examples takes approximately 30 minutes to go through.

2. Descriptions of Demonstrations and Videos

This section describes the demonstrations and how the instructors used each in the classroom setting. In the typical Fluid Mechanics course, there is a great deal of material to cover in a short time, making it difficult to include hands-on activities or demonstrations. Some demos described below take very little time and can sometimes be included while lecturing and/or passed around the class without taking any significant time out of the lecture. Some are used as part of examples that are worked in class and may or may not take extra time, and some, particularly the videos, can take up to 10 minutes away from the lectures. Of course a reader can pick and choose demos that best fit into his or her course. The author has most recently been teaching the course with a partially-flipped format. The students fill out lecture notes prior to class and the instructor provides just a short summary lecture with examples. This leaves extra time for demos and for the students to complete in-class problem solving. The demos below are introduced in the order in which the topics typically occur in fluid mechanics textbooks.

2.1. Introduction to Fluid Mechanics, Properties, and Classifying Flows

Topics in this section include introductory material, illustrating how complicated and surprising fluid motion can be. The section also includes demos on viscosity, small gap approximation, and cavitation.

2.1.1 Video of Bullet Under Water – generates interest in fluid mechanics

This *YouTube* video (link: https://www.youtube.com/watch?v=cp5gdUHFGIQ) is entitled "AK-47 Underwater at 27,450 frames per second (Part 2) - Smarter Every Day 97" and was discovered by a student who was interested in guns. It is now used by the instructor on the first day of class, mainly to generate interest in fluid mechanics.[11] The video is 10 minutes long and the young narrator describes bubble dynamics, sonoluminescence, pressure vs. velocity, cavitation, and shock waves in a captivating way (see figure 1).

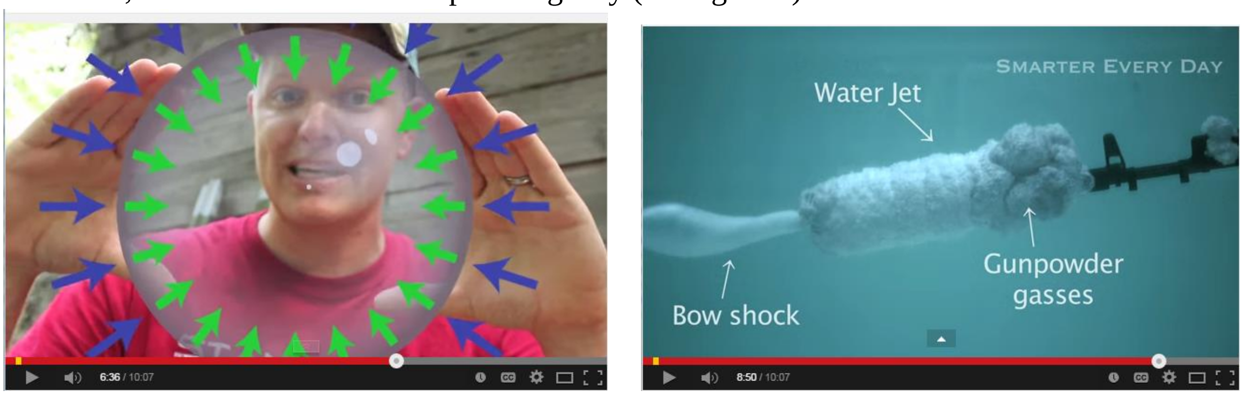


Figure 1: Screenshots from the bullet video[11]

2.1.2 Air Flow Between Disks – shows that fluid mechanics can be non-intuitive (and/or demonstrates Bernoulli's principal)

Like the gun video, the disk demo can be used to generate interest and also gives the instructor an opportunity to reiterate the relationship between pressure and velocity. The apparatus just takes a few minutes to construct out of common materials and can be completed in class in about 2 minutes. The author normally shows this on the first day of class and sometimes repeats the demo when covering the Bernoulli equation.

The materials for this device are: 1) two 4.25-inch circles cut out of thin cardboard, 2) a 1¾-inch-long stick pin, 3) a straw, and 4) glue. First the stick pin is pushed through the center of one of the cardboard circles. It is then glued in place on the side with the head of the pin, but gluing is optional. Next, a straw-sized hole is cut through the center of the other circle and the straw is inserted into the hole so the end is flush with the bottom side and the straw is perpendicular to the disk, like an axle (see figure 2). The straw should be glued in place to create an air-tight seal between the cardboard and the straw.

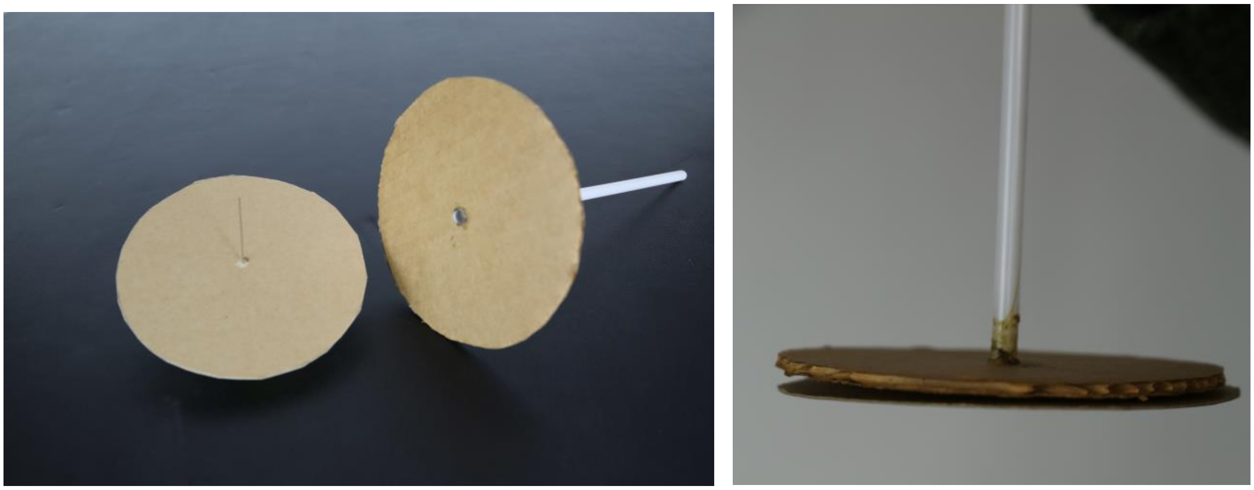


Figure 2: Two components of the apparatus and the demo in action. Note the bottom disk is very close to the top

During class, the instructor shows the two pieces of the device to the students, walking around to make sure all students get a good look. The instructor then holds the straw disk so that the straw is pointing up and inserts the pin from the other disk all the way into the bottom side of the straw, holding the bottom cardboard in place flush with top disk. Now the students are asked what will happen when the instructor lets go of the bottom disk. Hopefully, they will say that it will drop to the floor. The instructor then releases the bottom disk and, as expected, the disk falls. After picking up the bottom disk and reinserting the pin, the instructor asks what will happen if someone blows through the straw and releases the bottom disk. Usually the students' first reaction is to say that the disk will fall faster because the air in the straw is pushing on the bottom disk. However, after thinking about it, a few may remember from Thermodynamics or Physics (or the bullet video that they recently watched) that pressure decreases with increased velocity and, since they suspect a trick, will determine that maybe the disk won't fall. Still holding the straw apparatus with the straw pointing upward, the instructor blows into the straw and releases the bottom disk (figure 2). The bottom disk doesn't fall until the airflow stops.

When the instructor uses this demo on the first day of class, the "trick" is explained by discussing how the air flowing over the top of the bottom disk creates a shear stress that "pulls" on the surface, thus lowering the pressure. This is normally accompanied by rubbing one hand over the other to illustrate shear. When the demo is performed later in the semester, the Bernoulli equation is used to show that with positive velocity on the top and zero velocity on the bottom of the bottom disk, the pressure will be lower on the top. This can also be related to lift on an airplane wing.

2.1.3 Slippery Cards – demonstrates shear stress and the difference between solid and liquid. As a sideline it also shows the small gap approximation and the no slip assumption.

The technical definition of a fluid is "A solid can resist a shear stress by a static deflection; a fluid cannot."[12] This demonstration uses a deck of playing cards and a rubber band to help illustrate this concept and shouldn't take more than 3 minutes. For the first part of the demo, the rubber band is placed longwise around the deck of cards (see figure 3). If the rubber band is too loose, it can be looped twice. The instructor shows the cards and indicates that with the rubber band on the cards, the deck acts like a solid. After asking the students for a definition of stress and the difference between normal and shear stress, the instructor mentions that in fluid mechanics we call normal stress pressure, and shows pressure by using both hands to push on both the top and bottom saying that this is what happens when pressure is applied to a solid (basically nothing unless the pressure is very high). Shear stress is applied to the deck by moving the top hand parallel to the cards longwise. Here it could be noted that the top card will move with the hand, thus illustrating the no-slip condition. The deck of cards will deform until the rubber band is stretched enough to offset the shear. The students should know that this is what happens when a solid is subjected to shear, it will deform until its molecular bonds resist the shear. Note that the edge of the cards at this point could also be used to demonstrate the linear velocity profile of the small gap approximation. After letting go, the cards should bounce back to their initial position. The rubber band is then removed and the students are asked what will happen if the same shear is applied to the cards now that the rubber band has been removed. They should see that the cards now act like a liquid and will continue to move relative to each other until they fall on the floor. The instructor demonstrates this, stopping before the cards fall.

Figure 3: Cards under shear with the rubber band

2.1.4 Hot and Cold Honey – shows a high viscosity fluid and that viscosity is a function of temperature

For this quick demonstration, the author uses a 400 ml beaker filled with approximately 250 ml of honey. To demonstrate the behavior of a viscous fluid, the beaker is held at the top and swirled. As expected, the honey doesn't move much. The instructor microwaves the honey for approximately 20 seconds so that the honey is hot, but not so hot that a student could get burned. After warming the honey, the instructor swirls the honey again, demonstrating how heating the honey drastically decreased its viscosity. The beaker can be passed around as long as it isn't too hot. If a microwave isn't available, a hot plate could be used. An alternative would be to bring two beakers of honey, one hot and one cold.

2.1.5 Cornstarch Video – illustrates a non-Newtonian, shear thickening fluid

This very entertaining *YouTube* video of a segment from *The Ellen Show* (https://www.youtube.com/watch?v=RUMX_b_m3Js) is a little over 2 minutes long and illustrates how a dilatant, or shear-thickening fluid, increases viscosity to the point of acting like a solid if exposed to high shear. In the video an audience member walks across a vat of a cornstarch/water mixture (see figure 4).

Figure 4: Clip from the cornstarch video[13]

2.1.6 Stokes flow demo – shows an interesting phenomenon relating to high viscosity, no slip, and the small gap approximation

At very low Reynolds numbers, fluids have negligible inertia. This demo uses boli of dye inserted into corn syrup within a couette apparatus. By spinning the inner cylinder, the boli are deformed into streaks and then "unspun" back to their original shape, almost like magic. The author uses this demo to illustrate the effects of high viscosity when discussing shear stress, typically in conjunction with a couette flow small gap example problem, such as the problem P1.44 in White's 7th edition of the textbook *Fluid Mechanics*.[12] The instructor also reminds the students of this demo later in the semester when discussing the inertial terms in the Navier-Stokes equation.

The idea for this came from an old video that was shown by Dr. John Cimbala in a graduate Fluid Mechanics class in the 1990s. A few years ago, the author found and showed a newer 2 minute *YouTube* video of this phenomenon (https://www.youtube.com/watch?v=p08_KlTKP50) to the class. After seeing the video, a group of students decided to construct the demo as part of a laboratory project, so now the instructor does a live demonstration with the student-constructed device (see figure 5). One advantage of the live demo is that after turning the handle just a little, a linear velocity profile might be revealed from the top view.

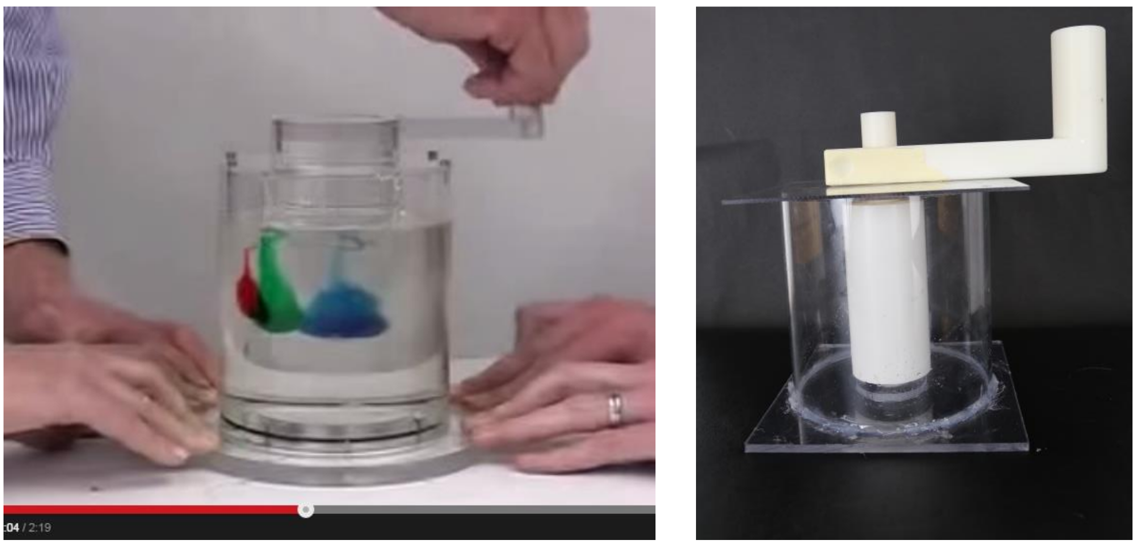


Figure 5: Clip from the Stokes flow video[14] (left) and the author's apparatus (right

Plans for building this demo can be purchased from the website: http://www.flintbox.com/public/project/6027/, but the students were able to construct a device just by watching the video. The inner cylinder is made of 2 1/4-inch PVC pipe and the handle and PVC pipe inserts were 3D printed. The outer tube was made from a 6-inch diameter acrylic tube and the top and base were made from plexiglass sheets that are also readily available (see figure 6). To create the dye boli, powdered fabric dye was mixed with the corn syrup and heated until the powder dissolved into the fluid. This works well, but if the dye is left in the device, it will eventually sink because fabric dye is a bit more dense than the corn syrup. Since the author has two sections of Fluid Mechanics, the dye from the first section stays in the device, eventually sinking to the bottom and a new set of boli are inserted during the second section. Also, since no pipette was available at the time of the demo, a syringe with a small tube was used to insert the dye.

Figure 6: Individual parts of the Stokes flow device

2.1.7 Cavitation demo

Like the Stokes flow demo, students attempted to create this demo, but it hasn't been completed at this point. It is basically a piston/cylinder device filled with water. The piston is lifted using a pneumatic cylinder, reducing the pressure and producing cavitation. Information, video, and directions can be found on the blog created by Nigel B. Kaye (see figure 7)[8] If a live demonstration of cavitation is too difficult to achieve, there are many images and videos of cavitation online. The author uses a homemade video in which students at the authors' institution test the effects of cavitation on fish.

Figure 7: Cavitation Apparatus from Kaye's online blog about demonstrations for Fluid Mechanics[8]

2.2 Fluid Statics

Topics in this section include pressure, pressure measurements, flat surface forces, and buoyancy.

2.2.1 Tall Tube – helps students understand that pressure is not a function of container size

To illustrate that pressure is not a function of container shape, the students are shown a 4-foot length of ½-inch clear acrylic tube held vertically with the bottom resting on the floor. They are then asked to imagine a three-foot diameter tank of the same height sitting next to the vertical tube, both filled with water. Several questions are posed; Which has the highest pressure at the bottom?, What if the tube and tank were a mile high?, and What if the small tube was filled with sludge? They are also asked if they sit at the bottom of a pool six feet deep does that feel any different than if they sit at the bottom of a 6-foot-deep large lake, and if having a rock next to you in the lake makes any difference.

2.2.2 Russian Dam Disaster – shows catastrophic effects of high pressure

The Sayano-Shushenskaya dam in Siberia suffered a major malfunction in 2009, killing 76 people. This 2-minute YouTube video, https://www.youtube.com/watch?v=SWcdDwECZU0, contains a presentation that describes the disaster and surmises that a log caught in the wicket gates induced a water-hammer effect and caused the extensive damage. It demonstrates some possible effects of the large pressure forces on submerged objects such as the upstream side of a dam.

Figure 8: Clips from a YouTube video of a presentation on the disaster at the Sayano-Shushenskaya dam in Siberia[15]

2.2.4 Disassembled Pressure Gauge – reinforces the relationship between pressure and force, shows the students how a pressure gauge works, and displays inches of water

There are many types of pressure gauges. Most measure a deflection resulting from net pressure forces in a tube or on two sides of a diaphram. A spare pressure gauge was disassembled so that the students could see its inner-workings. The instructor simply holds it up, explains how it works, and passes it around the class while continuing to lecture. Figure 9 shows the author's gauge, which is a fairly old Magnehelic differential gauge produced by Dwyer. A difference in pressure between the two ports causes deflection of a diaphragm which is connected to a flat, cantilevered spring. When the flat spring moves downward, it turns a screw that is attached to the needle, thus giving a pressure reading. An added advantage of this particular gauge is that it measures pressure in inches of water, so it also provides another opportunity to talk about pressure units. New dial gauges of various types can be purchased for under $20 each if a spare isn't available.

Figure 9: Disassembled pressure gauge

2.2.5 Manometers / Coiled manometer

At the start of the manometer discussions in fluid statics, the author brings two manometers from the laboratory to class, a u-tube water manometer filled with water and food coloring, and a small slanted manometer with red oil as the working fluid. One side of the larger water manometer is attached to a hand pump and demonstrated for the class (see figure 10). Manometers become very intuitive to the students when they see the fluid move as a result of increased pressure on one side. The small manometer has a slanted gauge and the instructor discusses how the slant allows for precise readings of small pressure differences. This demonstration also provides an opportunity to discuss mm-Hg or inches of water as a pressure unit. If a u-tube manometer isn't available, one can be constructed out of flexible tubing and a ruler connected to a board. If a hand pump meant for pressure calibration is not available, a blood pressure bulb pump, or bicycle tire pump could be used in its place and can be purchased inexpensively.

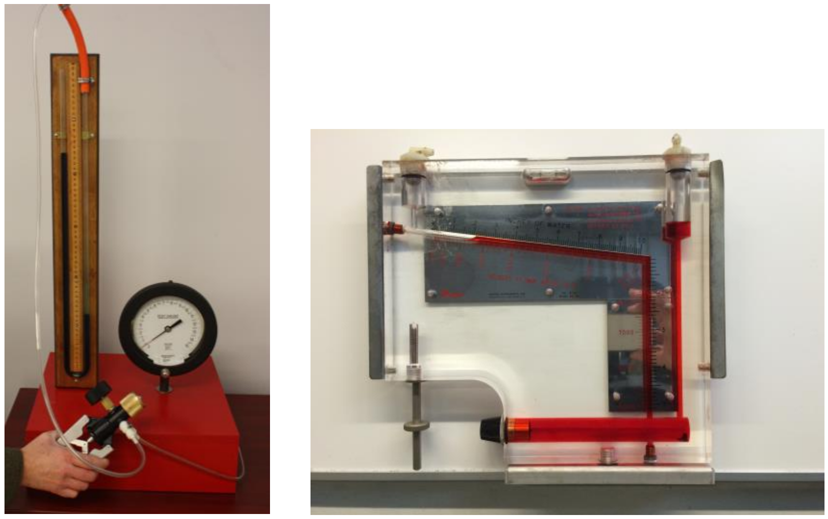


Figure 10: Manometers used in demonstration

Another demo that the author has not yet tried, but looks very interesting is a coiled manometer as described in Nigel B. Kaye's blog.[8]

2.2.6. Sinking car example and video – illustrates pressure on flat, submerged surfaces

It can take thousands of pounds of force to open a car door under water. This example and video combination provides an example of pressure forces on flat surfaces that students can easily relate to. One of these example problems is listed on the *EngageEngineering* website: (see figure 11).[4] The instructor uses this example as given and then also with the door hinge at the top (as in the Delorean featured in the film *Back to the Future*) so that the center of pressure comes into play and moments must be summed. After the example, an entertaining 7-minute *YouTube* video from a Canadian television program with "Rick and Dr. Popsicle," https://www.youtube.com/watch?v=UZuZgSQZJ9g, is shown. In the video, the characters show how the door cannot be opened when submerged and how they should escape (see figure 11).

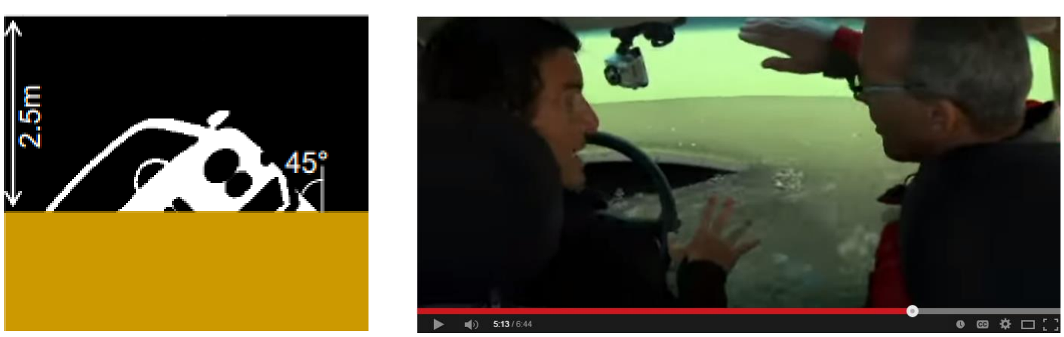


Figure 11: Picture from EveryDay Examples in Engineering (E^3)[4] (left) and clip from *Rick Mercer Report, Rick and Dr. Popsicle*[16] (right)

2.2.7 Upside-down cup of water – shows atmospheric pressure acting on a flat surface and vacuum pressure inside a container

This "magic-trick" demonstration fits well with a discussion of barometers or pressure on horizontal flat surfaces and only takes about two minutes. A cup with a smooth edge is mostly filled with water (the author uses a coffee cup) and a smooth, light piece of cardboard, such as a postcard, is placed on the top (the author cuts out a square from the cover of a phone book). While holding the cardboard in place, the cup is quickly turned upside down. The instructor can then let go of the cardboard and it should stay in place due to the vacuum pressure created inside the cup and atmospheric pressure acting on the bottom of the cardboard. It's a good idea to complete this "trick" while holding it over a container just in case air leaks in and the water comes pouring out. This demonstration is described in problem P2.27 from White's *Fluid Mechanics* textbook, 7th edition.[12]

2.2.8 Ball-Plugging-Hole Demonstration – shows that buoyancy comes from a higher pressure on the bottom of a submerged object

The idea for this demonstration came from problem 3.106 in the 8th edition of *Fox and McDonald's Introduction to Fluid Mechanics*.[17] The problem depicts a sphere covering a hole in the bottom of a water-filled container and questions whether the sphere will stay at the bottom or float. The instructor uses this problem as an example and then shows the live demo. The demonstration itself takes approximately 3 minutes. The initial idea was to create a demo in which the sphere blocks the hole completely and stays seated at the bottom. It was difficult, however, to get an air-tight seal between the sphere and the container. What actually happened turned out to be more interesting.

First, the instructor drops the ball in a bucket of water to show that it floats. The container is then placed on the top of a bucket or large beaker. The ball is held in place over the hole in the bottom of the empty container while a student volunteer fills the container with water from a pitcher or bucket until the container is close to full. The instructor then releases the sphere. The sphere stays at the bottom of the container while water slowly leaks out. When the water level drops to the point that the force on the top of the sphere no longer balances the buoyancy and weight forces, the sphere shoots to the top and the water comes rushing out of the hole until the water level drops enough that weight overcomes buoyancy and the sphere again drops to the bottom, possibly blocking the hole again.

The author used an ear-plug container (with the label removed) to hold the water because it happened to be available, it has a flat bottom, and is transparent (see figure 12). The container (with ear plugs) can be purchased from Amazon.com for approximately $70, but any large, clear container with a flat bottom could be used. The sphere is a 3 1/2 –inch hollow aluminum ball intended for use in a wind tunnel, but wasn't being used for this purpose. Since it had a hole it in, duct tape was used to cover the hole. This particular sphere weighs 178 g. Other waterproof spheres with smooth surfaces that normally float, such as a toy, could certainly be used. To approximate the minimum hole size for the bottom of the container, the following equations were used:

$$F_B = Buoyancy\ Force \approx \gamma V_{sphere\ minus\ cylinder} = \gamma\left(\frac{4}{3}\pi r_{sphere}^3 - \pi r_{hole}^2 d_{sphere}\right)$$

$$F_p = Pressure\ Force\ on\ Top \approx \gamma h \pi r_{hole}^2$$

$$W = F_B - F_p$$

The first two equations are substituted into the third and the resulting equation is solved for r_{hole}, where $\gamma =$ the specific weight of water and $h =$ the water height measured from the water surface to the top of the sphere. For the author's sphere and a water height of 3 inches, the minimum hole size was calculated to be approximately 1.5 inches in diameter, so a 1.75-inch-diameter hole was cut in the bottom of the container using a drill press. Sandpaper was used to smooth the hole and create a beveled edge so the sphere would seat better into the hole.

For class, the instructor brings the sphere, the container with the hole in the bottom, a bucket or other container to catch the water, and a pitcher or bucket of water to pour into the apparatus.

Figure 12: The earplug container that was used (left) and the author's container with hole in the bottom and sphere (right)

2.3 Control Volume Analysis

Topics in this section include flow rate measurement, forces from impinging water, thrust, relative velocity, and the Bernoulli equation.

2.3.1 RankineCycler^{TM} Beaker (Container with a Valve near the Bottom) – demonstrates volumetric and mass flow rate

This quick demonstration is used to show the meaning of volume and mass flow rate and how to measure flow rate with a beaker and stopwatch. The author uses a beaker that came with a RankineCycler^{TM} experiment, but any flow exiting a tube or hose can be used. The RankineCycler^{TM} beaker can be purchased by itself from the company Turbine Technologies, Ltd, but is quite expensive (approximately $250.00) because these beakers are CNC machined from cast acrylic and made in small batches (see figure 13). Something similar can be easily homemade using a bucket and spigot or valve purchased at any hardware store and directions can be found on-line. Note that it will be easier to get a watertight seal where the spigot connects to the bucket if a flat-sided bucket is used, such as those sold as livestock water buckets.

Figure 13: The RankineCycler^{TM} beaker used to demonstrate flow rate

For this demo, the instructor brings the half-filled RankineCycler^{TM} beaker, a 1000 ml beaker, and a scale to class. During class, the valve at the bottom of the beaker is opened and water is allowed to flow into the 1000 ml beaker while a student times the process. When the beaker is about ¾ full, the instructor quickly closes the valve, simultaneously asking the student to stop the timer. The volume that drained into the beaker and the student's time is used to calculate the volume flow rate. Also, the cross-sectional area of the outlet is used to calculate the average velocity of the water at the exit. The water is then poured back into the container and the beaker is set on the scale so the scale can be zeroed. The demo is then repeated and the mass flow rate can be calculated using the weight of the water in the beaker. The mass flow rate can also be calculated from the volume flow rate and compared to this result.

2.3.2 Impinging Water Jet Demo – shows how turning a flow through a higher angle will cause an increased force

This demonstration takes a more elaborate setup than most, and may already be included as a fluid mechanics experiment in the reader's engineering program. The author's apparatus was constructed as a student project (see figure 14), but can be purchased through laboratory manufacturers such as Armfield. Since the apparatus has been assembled on a cart, it can be wheeled into the classroom. The device pumps water upward where it exits through a nozzle, creating a jet. Various shapes can be inserted into the device to turn the jet through a range of angles. The force from the jet is measured using weights and moments. In class, the instructor first does an example in which the jet impinges on a flat plate. The example is then repeated with the jet striking a cup which turns the water 180°. Results from these examples show that the cup will experience twice the force of the flat plate. The example is now demonstrated. The cup ends up taking approximately double the weight to balance the force of the jet. The instructor also discusses possible errors associated with this experiment, particularly with the assumption that gravity can be neglected.

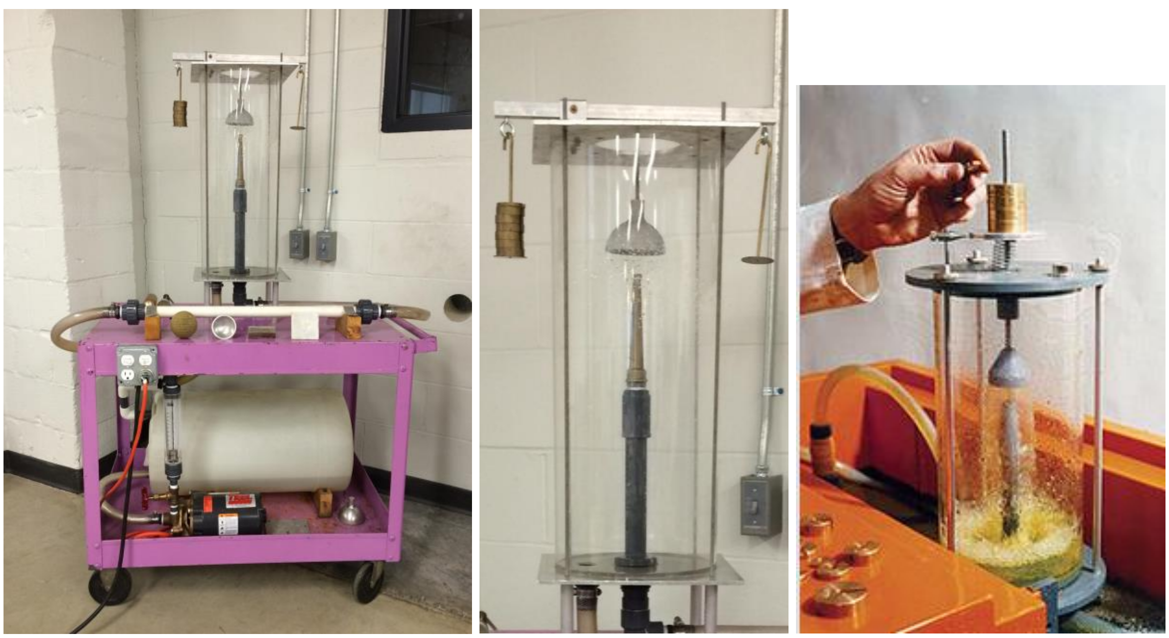


Figure 14: Author's impinging water jet apparatus (left and middle), Armfield's apparatus (right)

2.3.3 Pasco Super Fan Cart with and without Sail – demonstrates thrust and choice of control volumes

This fan cart was borrowed from a physics lab for this demonstration. The cart can be purchased at Pasco for approximately $200 or built much less expensively (see figure 15). The author uses it to discuss forces on various control volumes and starts by writing the momentum equation on the board. For the main part of the demo, the sail, or deflector, is removed. The fan is then turned on and the cart moves in the opposite direction of the air flow. The students are asked that if the mass flow rate at the inlet equals the mass flow rate leaving the fan, where is the force coming from and why is the cart moving? The instructor explains that we can examine this problem with several different control volumes. The first has an inlet in front of the fan and the outlet behind, possibly shaped like the sketch on the right in figure 15. For this case, the pressure forces are atmospheric everywhere and cancel out of the equation. However, the velocity in the axial (x-) direction is much higher at the exit than at the inlet, thus creating the thrust. Another way to look at the problem is to put the entire control volume inside the tube that encases the fan with the inlet in front of the fan and the exit just behind the fan. Here, the inlet and exit velocities are approximately equal and the velocities cancel out of the equation. However, the fan acts like a compressor and will increase the pressure downstream of the fan, thus creating a pressure force and the thrust. A third control volume surrounds just one fan blade. A cut through the blade shows an airfoil shape. When spinning, the blade acts like an airplane wing and produces lift and that is what causes the thrust.

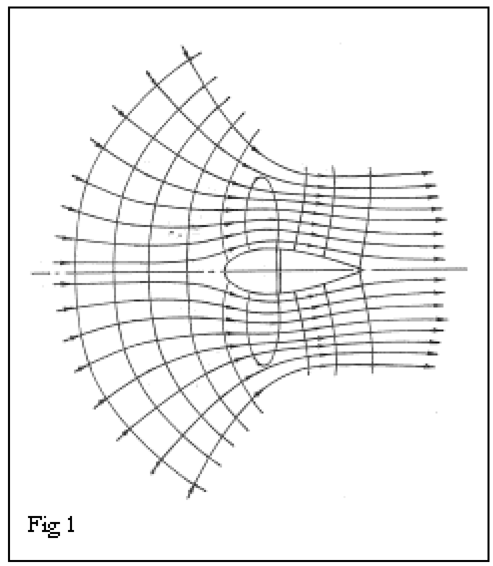


Figure 15: Pasco Super Fan (left), propeller flow field (right)[18]

After the control volume discussion, the instructor references the impinging water jet demonstration (Section 2.3.2) and asks what will happen when the sail is attached so that the air is turned 180°. The sail is attached so that the air is turned and the cart then moves in the opposite direction. Finally the students are asked what happens if the sail is turned around so that most of the velocity (inlet and exit) is moving in the radial direction. The sail is turned around and the demonstration shows that the cart barely moves.

2.3.4 Tube with Action Figure – helps the students determine relative velocity values

Students often have trouble adjusting velocity when confronted with a moving control volume. To help the students understand when to add or subtract the velocity of the control volume to find the relative velocity, an action figure from the video game "Halo" (the character is named “The Chief” according to the students) is attached to the top of a small length of 2 ½-inch PVC pipe using a rubber band (see figure 16). The students are told that forces on the control volume are calculated based on what the control volume “feels,” and that they should pretend that they are “The Chief.” The tube with Halo figurine is then pushed axially through the still air like a child might use a toy airplane. The students are asked which velocity to use when calculating the inlet and exit velocity for the tube and also what velocity to use when calculating the mass flow rate. A fan is then turned on and the demo is repeated with the tube and action figure moving towards the fan as the fan blows air at The Chief. The students are reminded that they need to “be one with The Chief” and then again asked which velocity to use. Lastly, the tube and figure are moved away from the fan and the students are again asked about the relative velocity. This is a silly demonstration that seems almost trivial, but the author found many opportunities throughout the remainder of the semester for which reminding the students of Halo and the fan was helpful. Of course, any action figure will do. Gumby or Barbie would be good alternatives to the Halo figurine.

Figure 16: “The Chief” sitting on his tube

2.3.5 WindBag – demonstrates the relationship between velocity and pressure

A fun, inexpensive, and quick example of Bernoulli’s relationship between pressure and velocity is the WindBag or Bernoulli Bag which can be purchased for approximately $7 for a pack of 4 from Arbor Scientific or Amazon.com. The instructor first gathers up the open end of the bag and blows into it with several breaths like a person would do to inflate a paper bag. It is clear that it will take a long time to fill the bag up this way. The instructor then opens the end, takes a deep breath, and is able to fill the bag with one big breath (see figure 17). This generates discussion about Bernoulli and how the breath velocity induces a low pressure that in turn entrains enough air to fill the bag. Since these bags are inexpensive, they could be purchased for every student, although it might be difficult to fit many inflated WindBags into one classroom.

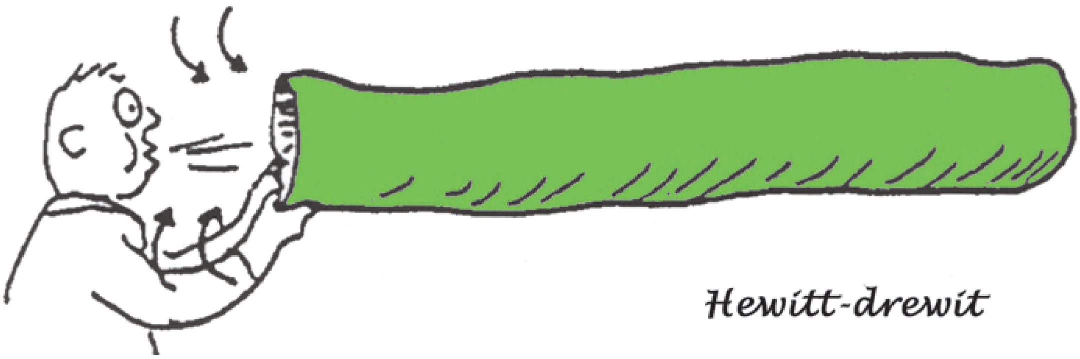


Figure 17: Bernoulli Bag image from the Arbor Scientific web page

2.3.6 Air Flow Between Disks Repeat – demo on pressure vs. velocity

See section 2.1.2. Now that students have studied the Bernoulli equation, they can better understand what is happening with the disks.

2.3.7 Papers on the Board –demonstration of pressure vs. velocity and the no-slip condition

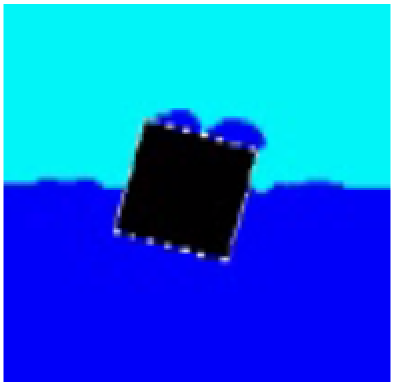
Another quick demonstration of the relationship between velocity and pressure can be completed by simply taping just the top of some scratch paper to the board at the front of the class and quickly walking by the papers. The velocity created by the movement (no-slip on the side of the moving person) will cause the bottoms of the papers to pull away from the board. The author has not tried this demo in class as of yet. The idea came when a student quickly walked by a bulletin board and some of the papers came flying out behind him.

2.4 Differential Analysis

This section deals with the continuity and Navier-Stokes equations.

2.4.1 Penn State Gas Dynamics Lab Video – categorizing flows to help create assumptions for Navier-Stokes solutions

When trying to solve Navier-Stokes problems, students often have trouble identifying the assumptions that they should use to eliminate terms. The 10-minute video called "Chapter 1 Introduction" that was produced by Dr. Gary Settles at the Penn State Gas Dynamic Laboratory and included with the 6th edition of Frank White's *Fluid Mechanics with Student DVD* does a great job categorizing flows and showing many different flow fields, both through flow visualization techniques and Computational Fluid Dynamics (CFD) solutions (see figure 18).[19, 20] Many of the categories, such as 2-D vs. 3-D and laminar vs. turbulent can help the students with their assumptions. The author also uses this video as a lead-in to a discussion about how the solution is a set of equations, about boundary conditions, and about the relationship between Navier-Stokes and CFD. Unfortunately, the only way to acquire the video is to find or purchase the 6th edition of the White textbook with the DVD. The video is not currently available on YouTube.



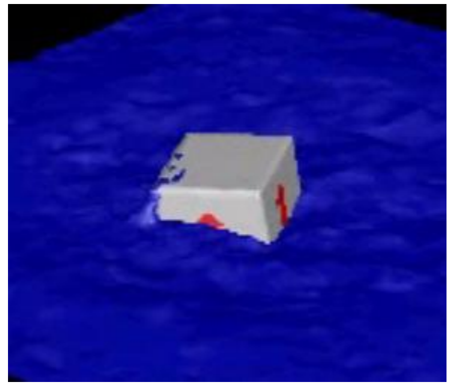
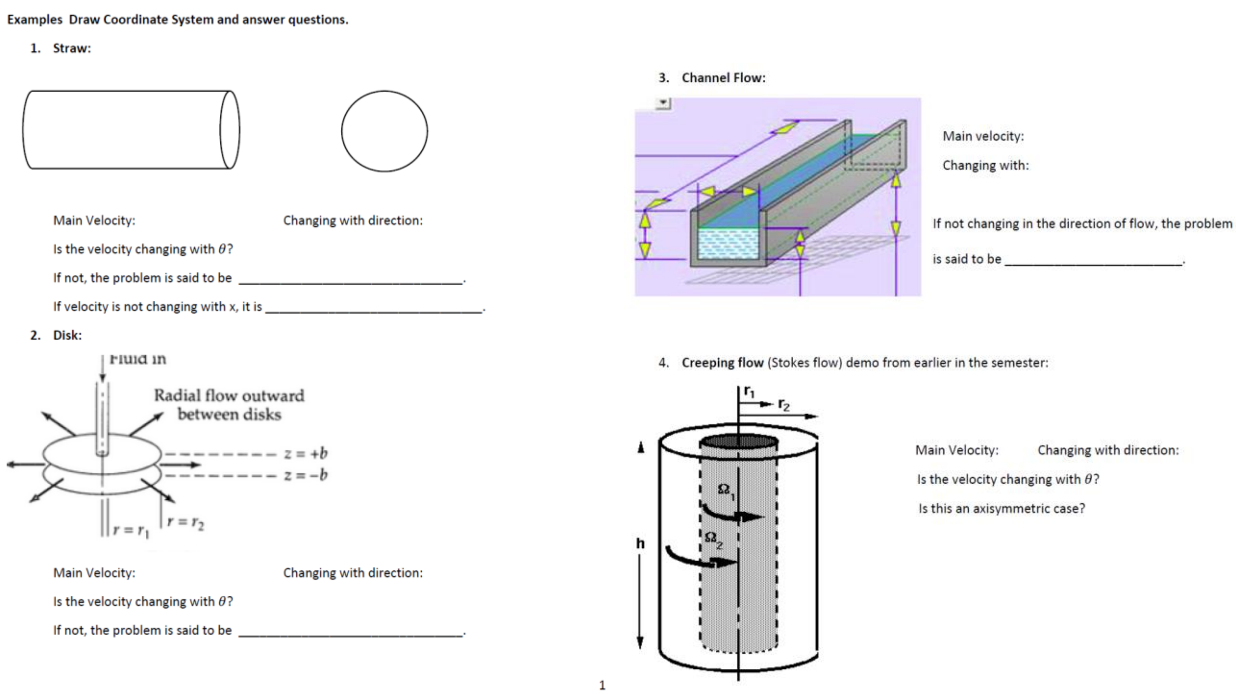


Figure 18: Clips from the Penn State video: 2-D CFD simulation (left), 3-D CFD simulation (right) [19, 20]

2.4.2 Worksheet on Coordinate Systems, assumptions, and flow directions – helps the students visualize flow directions, velocity derivatives, and to understand some assumptions

While not technically a demo, the instructor goes through this set of examples with the students in an effort to help them better visualize different types of flows and to understand coordinate systems, and axisymmetric and/or fully developed assumptions used in the solution of the Navier-Stokes equations (see figure 19). Several of the previous demos are referenced in this worksheet.



Examples Draw Coordinate System and answer questions.

1. **Straw:**

Main Velocity: Changing with direction:

Is the velocity changing with θ?

If not, the problem is said to be ______________________________.

If velocity is not changing with x, it is ______________________________.

2. **Disk:**

Main Velocity: Changing with direction:

Is the velocity changing with θ?

If not, the problem is said to be ______________________________.

3. **Channel Flow:**

Main velocity:

Changing with:

If not changing in the direction of flow, the problem is said to be ________________________.

4. **Creeping flow** (Stokes flow) demo from earlier in the semester:

Main Velocity: Changing with direction:

Is the velocity changing with θ?

Is this an axisymmetric case?

1

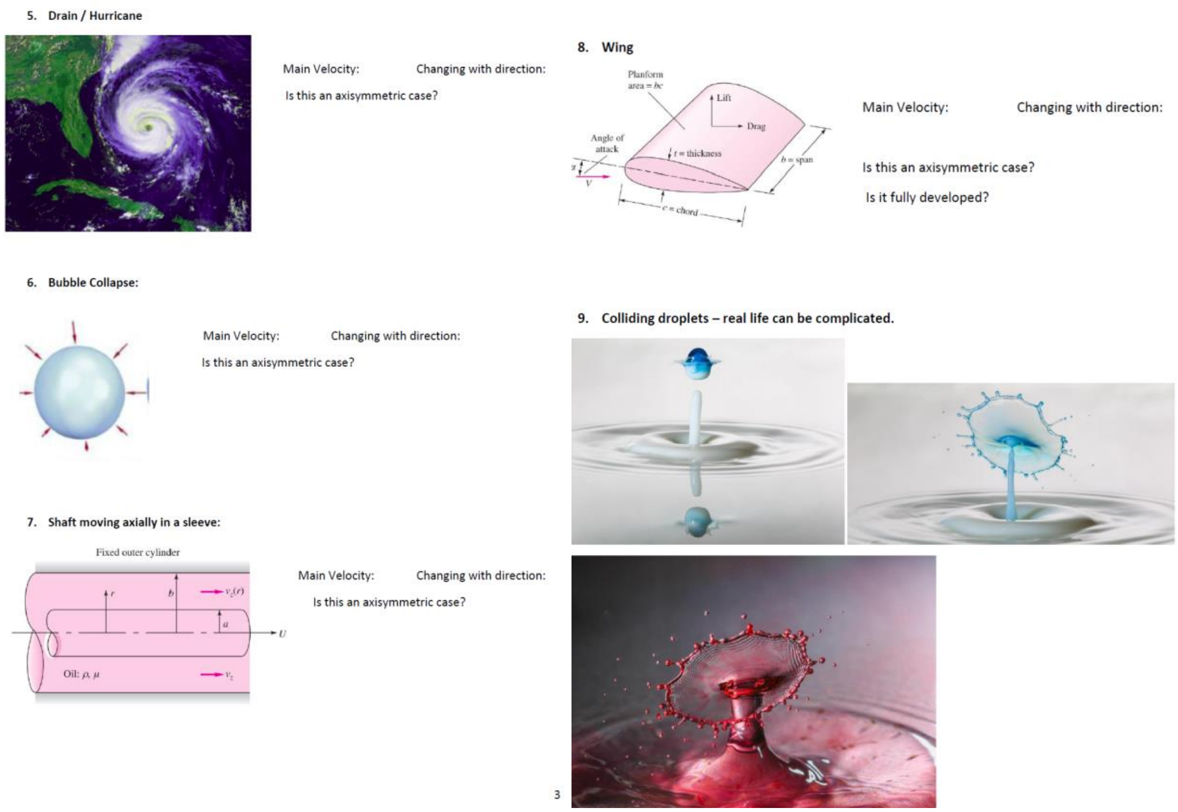


Figure 19 Pages 1-4 of the Worksheet Image references: Radial disk flow in number 2[21], Channel Flow in number 3[22], Couette flow in number 4[23], Hurricane in number 5[24], Bubble in number 6[25], Shaft in a pipe in number 7 and airfoil in number 8[12]

2.4.3 Jar on a Turntable – demonstration of a problem that can be solved using Navier-Stokes equations

One of the Navier-Stokes examples that is solved during class involves fluid inside a rotating cylinder. The solution results in solid body rotation. The author created a demonstration of this result by purchasing a toy pottery wheel from Walmart for about $20 and gluing an earplug container with the label removed (see section 2.2.8 for information on the container) to the tray. Note that other containers can be used, but they need to have a flat side in order to see the parabolic free surface. A horizontal line representing the original water level is drawn approximately one inch from the bottom of the container. For the demonstration, water with food coloring is poured into the container up to the reference line and the pottery wheel is turned on. Each time the flat side comes around, the students can see the parabolic water surface (see figure 20). It can be difficult to see the results, so the students sometimes need to come to the front of the room to get a good view. As an alternative, there are rotating fish tank videos available on YouTube, such as the one at https://www.youtube.com/watch?v=f8IwL2ZtDTc, that illustrate the same thing.

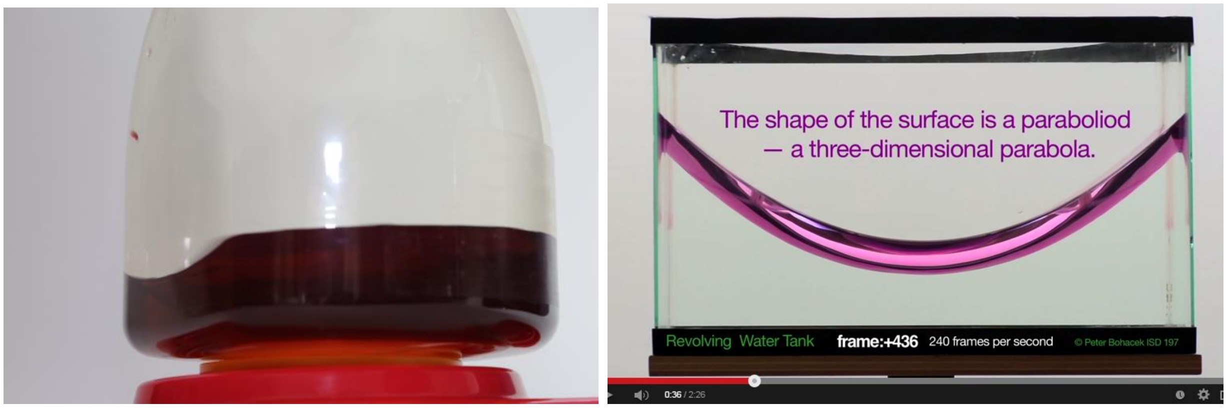


Figure 20: Solid-body rotation demo (left) and clip from a YouTube video (right)[26]

2.4.3 Stokes flow again – demonstration of a couette flow solution

See section 2.1.6. The author uses the Stokes flow demo in conjunction with the viscosity section of the course, but it could just as easily be used here with an example of the Navier-Stokes solution for steady laminar couette flow or a way to illustrate an unsteady solution that can be solved because the inertial terms cancel, leaving just an unsteady boundary condition (inside cylinder turning one direction, then reversing).

2.4.5 Syringe with Corn Syrup – illustrates a parabolic velocity profile for laminar flow in a pipe

As a final example in the Navier-Stokes section and a lead-in to pipe flow, the students solve the Navier-Stokes equations for laminar flow in a pipe. The result is a parabolic velocity profile. For this demonstration, at least an hour before class, corn syrup is poured into a beaker and fabric dye is sprinkled in and the corn syrup is heated in the microwave until it is warm enough that stirring dissolves the fabric dye (about 20 seconds). The corn syrup is then allowed to cool to room temperature. The instructor brings the dyed corn syrup, another beaker containing clear corn syrup, and a 30 ml syringe to class. During class, the instructor pulls clear corn syrup into the syringe until there is about 1 ½ inches of clear fluid in the syringe. The dyed corn syrup is then slowly pulled into the syringe until a parabolic profile is seen (this may take a little practice) (see figure 21). The syringe is then passed around the class with some paper towels under the tip.

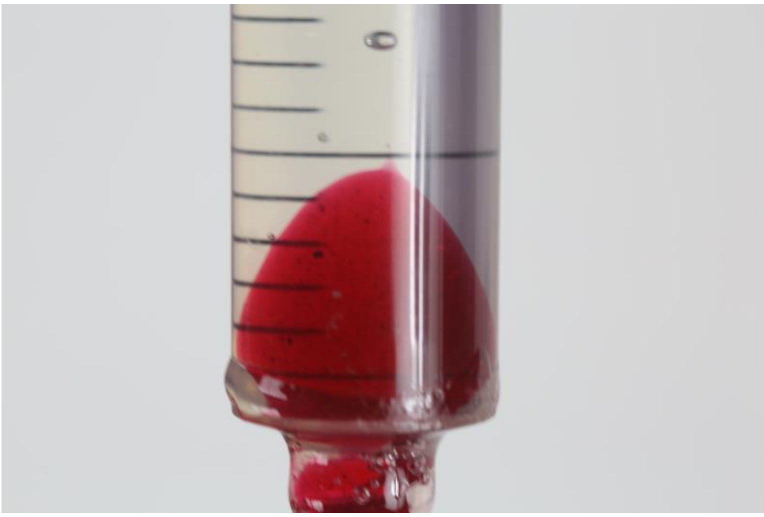


Figure 21: Syringe with parabolic profile

2.5 Dimensional Analysis and Similarity

This section includes scale modelling and similarity examples.

2.5.1 Hydroturbines – shows an application where model testing is important

The hydroturbine industry uses scale modelling extensively because the prototypes can be extremely large and expensive. The author's institution happens to have a model-sized Kaplan turbine and a small model pump/turbine. These are simply carried to class and shown along with an image showing the scale of some of the full-size machines (see figure 22). The class is told that with this much scaling, Reynolds number similarity cannot be achieved but the discrepencies due to this can be accounted for. Instead, the hydroturbine industry uses non-dimensional parameters such as $E\omega d$, representing pressure head, $Q\omega d$ for flowrate, and one called sigma for cavitation potential.

Figure 22: Prototype Kaplan Turbine (left)[27], Model-size turbines (right)

2.5.2 Scaled-Up Bullets – provides an example of scale modelling and promotes discussion of modelling pitfalls

The students at the author's institution are required to complete a project at the end of their Fluids laboratory course and many ask to use the wind tunnel to do scale modeling. Most of the time, this is not practical because the students want to scale down cars or other large objects and this means they need to scale up the velocity beyond the capabilities of the wind tunnel. However, scaling a small object up can sometimes work well. One group of students modeled bullets in the wind tunnel by 3-D printing several bullet designs and another group from a different year machined several pellet gun bullet shapes out of aluminum (see figure 23). The instructor brings some of these bullets to class and discusses the scale factors, how meaningful drag results can be found, and how compressibility may need to be considered.

Figure 23: 3-D printed bullets (left), Machined bullets (right)

2.5.3 House fire and "The Day After" – fun example of similarity

As with the Stokes flow demo, the idea to use these videos as an example of similarity came from a graduate level fluid mechanics course taught by Dr. John Cimbala at Penn State University. In this course the instructor referenced old movies in which house fires just looked "wrong." Back then, we remembered these old movies. He then went on to explain how they looked wrong because the Reynolds numbers associated with the model houses used in the movies was too low and therefore the ratio of large to small eddies was too small. The professor then went on to explain that this same Reynolds number issue was a problem when the producers were trying to develop the special effects for a 1983 movie about a nuclear war. They realized that it was going to be difficult to simulate the mushroom clouds realistically. Since they needed technical assistance, they hired a graduate student from Caltech to create realistic looking mushroom clouds for the movie "The Day After." This student used water jets released into fish tanks to produce the mushroom effect. He added small holes around the edges of the larger center jet to produce the small eddies so that the clouds had a high enough eddy ratio to look realistic. The special effects for this movie went on to win the Emmy award for 1984. It is fun to tell this story and show this example not only because most students enjoy movies and the special effects in old movies now seem funny, but because it is nice to see an engineer being celebrated in Hollywood.

For this demo, the author explains the problem with fires in old movies and then shows a *YouTube* video of a model house on fire. There are many out there, but here is a quick 18 second one: https://www.youtube.com/watch?v=KexwfFzYFt8. The story about the water jets and Emmy award is then relayed to the students and a clip from "The Day After" is played. The attack sequence can be found on *YouTube* at https://www.youtube.com/watch?v=7VG2aJyIFrA (see figure 24). The total video length is about six minutes, but the author starts it at about the 2 minute mark and continues for just a minute or two. The students are warned that although the special effects are outdated, the scenes are still somewhat graphic and viewer discretion is advised.

Figure 24: Scene from the 1983 movie "The Day After"[28]

2.6 Flow in Pipes and Ducts

Topics for this section include laminar flow, effects of diameter and length on frictional head loss, and minor losses.

2.6.1 Syringe with Corn Syrup – shows the parabolic velocity profile for laminar flow in a pipe

This demonstration was described above in section 2.4.5 because the author uses it in conjunction with a Navier-Stokes example. However, it could also be used to demonstrate laminar pipe flow as part of an introduction to pipe flow.

2.6.2 Straw demo – gives a feel for the effects of diameter and length on frictional head loss

This short demonstration is an inexpensive but effective way to give the students a feel for frictional head loss. After deriving the frictional head loss term in the energy equation, each student is given two straws, one a normal drinking straw, and one a small coffee-stirrer straw. The students are told to blow through the two straws. They are then asked a number of questions, such as:

- What are you doing with your mouth to make the air flow?
- How do you make the air go the other way?
- Which straw is easier to blow through and why?
- Referring to the head loss equation, how does diameter affect the head loss?
- How does length affect the frictional head loss?

Finally, scissors are passed around and the students are told to blow through one of the straws and, while still blowing, to cut the straw in half. This is a good way for the students to feel the effect of length for themselves. The author normally brings five or six pairs of scissors to class so it doesn't take long for each student to complete this little experiment.

Figure 25: Straws and scissors used in the frictional head loss demonstration

2.6.3 Diffuser Causing Increasing Flow – demonstrates an interesting example problem involving the energy equation for flow in pipes and minor losses associated with a diffuser

The idea for this demonstration came from problem P6.99 from White's *Fluid Mechanics* (see figure 26).[12] Stories have been told that some ancient Romans would add a diffuser to the end of their pipes to increase the flow of water from the aqueducts into their homes, thus receiving free water.[12] This demo, which takes approximately 5 minutes, is performed after doing problem P6.99 as an example and then describing how the diffuser decreases the pressure at the diffuser inlet to below atmospheric, increasing the ΔP between the water surface and the diffuser and thereby increasing the flowrate. The container used for this demonstration is the same one used for the flowrate demonstration, see section 2.3.1 RankineCycler™ Beaker (Container with a Valve near the Bottom), but another could be created. A student volunteer uses his or her cell phone to record the time it takes for the water a particular volume to exit, first without and then with the diffuser attached. For the RankineCycler beaker, a starting head of approximately 3 inches is used, ending at approximately 2 inches. For both cases, a bucket is placed under the open end of the tube or diffuser, the valve is closed, and the beaker is filled to just over the 1500 ml mark. The valve is then opened. When the water level gets to 1500 ml, the student starts the timer. When the level hits 1000 ml, the student stops the timer. If connection and diffuser losses are low enough, the time should be smaller for the diffuser case.

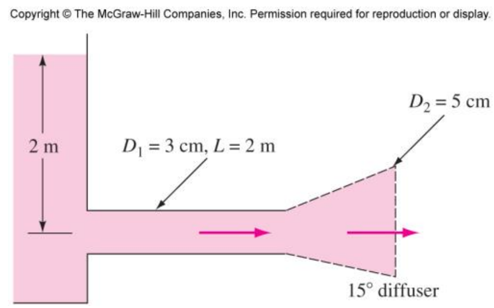


Figure 25: Figure from White's *Fluid Mechanics* problem P6.99[12]

It was tricky constructing a diffuser that wouldn't separate or otherwise have high losses and also to find a good water level for the container. Several iterations were required to get it to work. This paragraph describes how the final setup was created. The RankineCycler™ beaker has a valve at the bottom, and for the non-diffuser case was connected to a ¼–inch I.D., ½–inch O.D. clear plastic tubing approximately 3 ¾-inch long. This is the setup used for the non-diffuser case. The diffuser was constructed out of plastic from a report folder, duct tape, a 1-inch piece of the same ½-inch O.D. tubing, a 1-inch piece of ½-inch I.D. tubing, and a cable tie (see figure 26). To keep losses low, the small diameter tubing should be cut carefully so that it has a smooth, perpendicular edge. First, with the plastic report folder closed, both layers were cut to form two trapezoids the 11 ¼-inch length of the folder with a width of about ½-inch at the small end and 1 ½-inch at the wide end. A piece of duct tape was cut about an inch longer than the plastic pieces, placed sticky-side up on a table, and the two pieces of plastic were placed on the tape so that there was a small gap between their long edges and about a ½-inch of duct tape extended beyond the short side of the plastic. A narrower piece of duct tape was then cut and placed sticky side down over the gap between the plastic pieces. Another piece of duct tape was placed sticky-side up on the table and the edge of one plastic piece laid on top. A narrow piece of duct tape was then placed sticky-side down to cover the edge of the plastic and about 3/8-inch outside of the plastic. The small tubing section was then placed at the narrow end of the plastic so it extends just beyond the duct tape (see figure 26). The plastic and duct tape combination was now folded over and taped to form a diffuser with a tube at the narrow end. The last step was to push the tube on the diffuser about half way into the 1/2–inch I.D. tube to form a connector. A cable tie was added to help prevent leaks. Because no real precision was being attempted during construction, the sides of the author's diffuser range from about 1/8-inch high at the narrowest to about 1/4-inch high at the widest. Figure 27 shows the finished diffuser and the complete setup with diffuser attached.

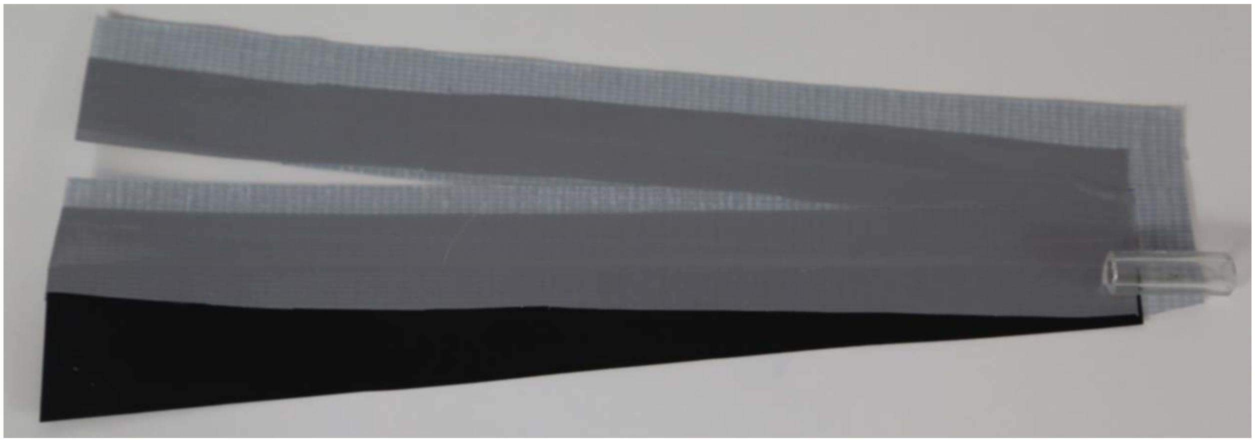


Figure 26: Construction of the diffuser

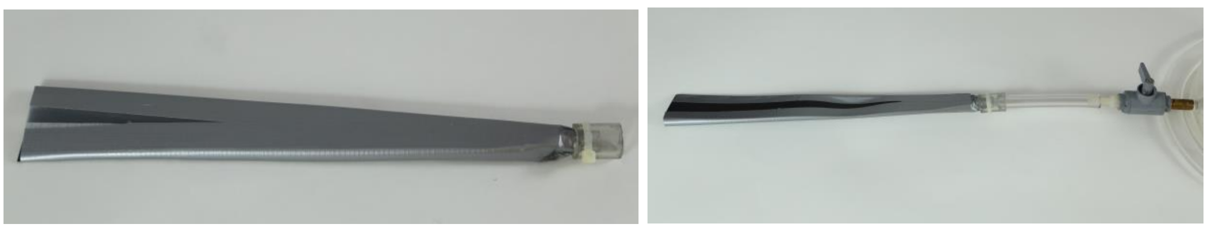


Figure 27: The diffuser (left) and the diffuser attached to the RankineCycler™ beaker

2.6.4 Valves – gives the students a better understanding of minor losses

This short demonstration just involves bringing different types of valves to class, explaining how they work and why they produce different minor losses, and passing the valves around the class. This could be done with venturis, elbows, or other fittings as well. The author brings ball, check, disk, and globe valves to the class so students can see their inner workings and operate the valves for themselves while the lecture continues.

2.7 External Flow

Demonstrations in this section illustrate lift, drag, and effects of separation.

2.7.1 Blow Over Paper – demonstrates how velocity creates lift

This is an extremely quick and easy demonstration. To illustrate how the higher velocity over the top of an airfoil or one side of a sail reduces pressure and creates lift, one can simply bring a sheet of scratch paper to class, hold it horizontally by the short end and blow over the top of it. The paper will quickly rise and flap like a flag (see figure 28). The idea for this demonstration came from an Old Dominion University physics department website: http://sci.odu.edu/physics/resources/Demonstrations/Fluid_Dynamics.html?#DynamicFluids.[9]

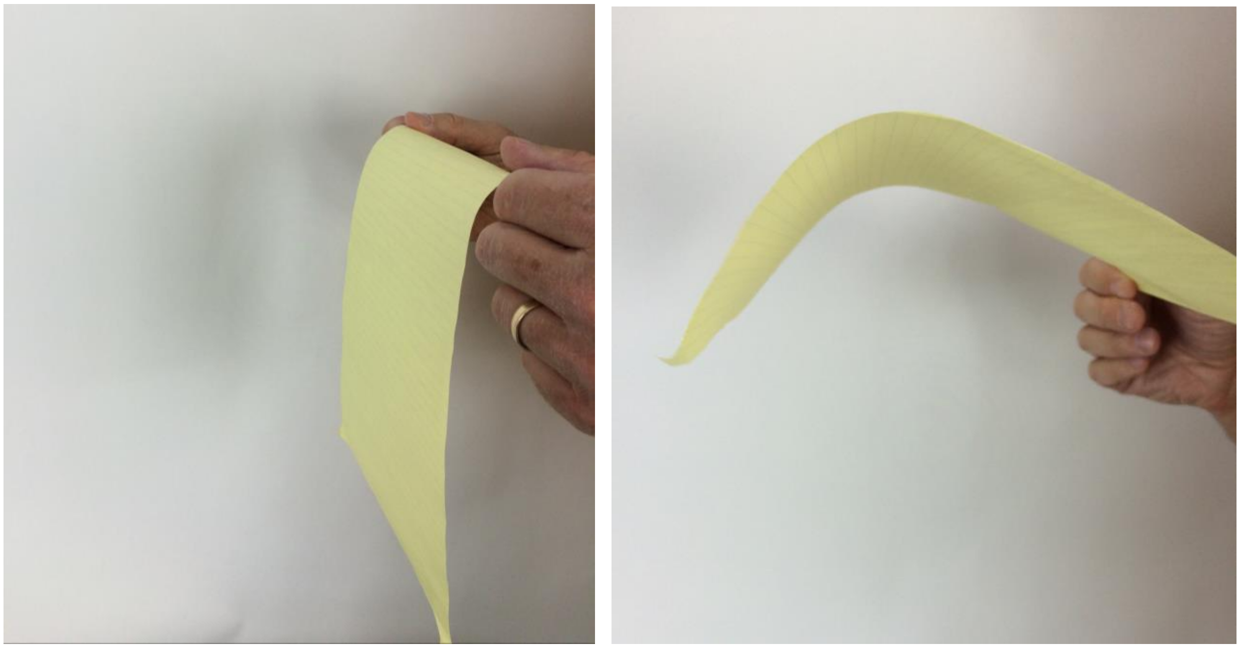
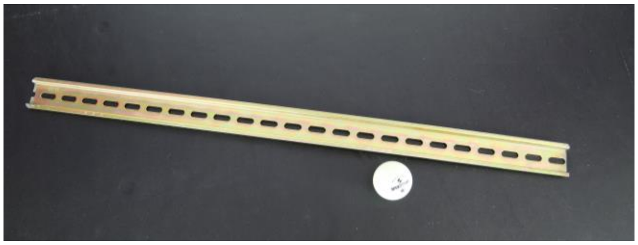


Figure 28: Blowing over paper (before and during the blowing process)

2.7.2 Ping pong ball curving – shows the effects of separation and wake angle on drag

Most students have experienced a curve ball, be it from baseball, soccer, golf, or many other sports, but most do not know why the ball curves. This demonstration is therefore very interesting to the students. The idea came from a Physics website posted by the University of Iowa.[29] Rather than constructing a thrower, the author found a bracket in a scrap pile in the shop (see figure 29). In class, the instructor stands at the back of the classroom, puts the ping pong ball on the bracket end near the hand and swings the bracket at about a 30° angle from the ground, allowing the ball to roll down the bracket before sailing over the heads of the students. With a little practice, the right-handed author was able to get the ball to start with a slow curve to the right, but near the front of the class, just beyond the front row of students, make a sharp drop to the left.

The explanation for this Magnus effect phenomenon can be as detailed as the instructor would like to make it. For the author's class, the effect is explained by drawing a sketch on the board similar to the Wikipedia sketch shown below[30] and explaining that the no-slip condition will cause the separation angle to be offset. With the skewed wake, the top of the ball in the sketch (corresponding to the right side of the ping pong ball) has a much bigger area exposed to the flowing air, and thus experiences lift. This is why the ping pong ball initially curves slightly to the right. The students are then reminded that the forces on the ball will be due to the relative velocities that the ball experiences. They are reminded of "The Chief" moving into and out of the wind in the demo described in Section 2.3.4 and asked which side of the ball will "feel" a higher velocity. Since the top part of the ball in the sketch is moving away from the flow, it will experience the lower velocity and thus a lower Reynolds number. As the ball slows due to drag, the boundary layer on the top will become laminar before the boundary layer on the bottom. At this point, the separation will move closer to the front of the ball on this side, suddenly changing the wake angle, and thereby causing the lift force to change from upward to downward in the sketch and the ping pong ball to suddenly veer to the left. This phenomenon can also be related to knuckle balls, for which the ball is not spinning much and the separation angle can switch unpredictably if thrown at a speed near transition. Also, the stitching or other bumps on certain balls (particularly baseballs) can alter this affect because they can trip the boundary to turbulent at a lower Reynolds number.



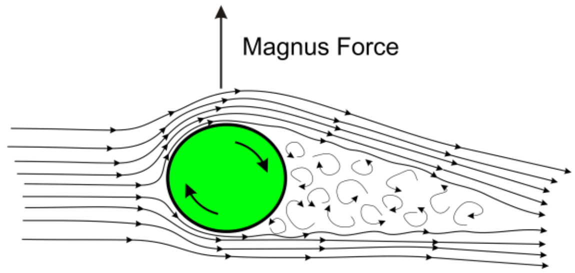


Figure 29: Ping pong ball demo equipment (left), Wikipedia sketch of flow around a spinning ball (right)

3.   Assessment

The grades in the course were a bit higher in this first "demo semester" than in many previous semesters, but the course was also changed from a traditional lecture format to a partially-flipped format, and our program has experienced a rise on average in academic abilities over the last few years. Because of these factors, grades themselves are not believed to be a good indicator.

As part of normal procedures, the instructors in our program administer an outcomes survey to assess the students' perceptions of their understanding of the concepts. To determine student attitudes with regard to the demonstrations, the instructor added a section to the survey addressing just the demos. Table 1 contains this section of the survey with the numbers of responses for each category.

Table 1: Attitude Assessment Survey with Results

Demos:

	Strongly Agree	Agree	Disagree	Strongly Disagree
The classroom demos are worthwhile:	13	19	2	1
The classroom demos helped me understand the concepts:	11	21	2	1
The demos made the topics more interesting:	19	12	4	
The demos help me remember how to apply the concepts when solving problems.	8	16	10	1

The results show that the overwhelming majority of students thought the demos helped them understand the concepts and made the class more interesting. Fewer, but still a majority, thought that the demos helped them solve problems.

Note that all of the “Strongly Disagree” responses came from the same student. This student also strongly disagreed that he/she had learned any of the topics in the course. There was a student in this group who had decided to change his major part way through the semester and didn’t need Fluid Mechanics, so quit trying. It is very possible that this was the student that “Strongly Disagreed.” Another interesting survey was one in which the student agreed that the demos were worthwhile, but disagreed that they helped with concepts or made the topics more interesting. He or she, however, “Strongly Agreed” that the demos helped when applying the concepts. Apparently this student didn’t really like the demos, but must have remembered them when solving problems.

This survey also had a comment section which asked them to list “Things I liked best about this course” and “Suggestions for Improvement.” Ten out of the 35 students listed the demos under the “Things I liked best about this course.” Nobody mentioned demos in the suggestions for improvement. Two elaborated that they liked the demos because they helped them understand the concepts. One said “They kept things interesting and it was nice to have a visual to look back on.” Another wrote “I also liked the demos a lot. They really helped with visualizing concepts.”

There is also a standardized course survey that is administered online, but there were very few comments on these surveys, possibly because the students had already commented on the in-class survey. There was one comment, however, that dealt with the demonstrations and it just read “more demos.”

4. Conclusions

This paper describes a wide variety of Fluid Mechanics demonstrations, almost all of which were used in class in the 2014 fall semester. There is no doubt that these demonstrations increased interest in the course. Most students also claimed that they helped them understand and apply the concepts. One thing that surprised the instructor is the number of times the demos were referenced in class after the fact. “Remember how The Chief felt in the fan,” or “remember how the disk didn’t fall to the ground” gave the instructor a great way to start answering a student’s question. Many times the student would say “Oh, yeah” and then go on to answer their own questions. Another surprising result was that students started emailing interesting fluid phenomena that they found online to the instructor or sometimes stopped by during office hours to discuss an interesting fluids topic that they found.

Developing and constructing the demonstrations or finding appropriate yet entertaining videos sometimes took some time, but the authors believe that it was very much a worthwhile endeavor. The demos will continue to be tweaked, modified, or replaced from time to time, but now that most are available, they will add very little preparation time to the course. The authors’ next steps are to make descriptions and videos of these demonstrations available online, and to start adding more demonstrations to other courses.

5. Bibliography

1. Prince, M. "Does Active Learning Work? A Review of the Research." *Journal of Engineering Education* 93(3) 223-231, 2004.

2. Smith, M. K. (2001, 2010). "David A. Kolb on experiential learning," *the encyclopedia of informal education.* [http://infed.org/mobi/david-a-kolb-on-experiential-learning/. Retrieved: Jan. 2015.

3. Schuman, L.J., Delaney, C., Wolfe, H. Scalise A. & Besterfield-Sacre, M. (1999). "Engineering Attrition: Student Characteristics and Educational Initiatives." A paper presented to the 1997 Annual Meeting of ASEE.

4. "What is Engage: Engaging Students in Engineering" *Engage: Engaging Students in Engineering.* [http://www.engageengineering.org/. Retrieved: Jan. 2015.

5. Olinger, D.J., Hermanson, J.C. "Integrated Thermal-Fluid Experiments in WPI's Discovery Classroom." *Journal of Engineering Education* 91(2) 239-243, 2002.

6. Linsey, J., Talley, A., White, C., Jensen, D., & Wood, K. "From Tootsie Rolls to Broken Bones: An Innovative Approach for Active Learning in Mechanics of Materials." *Advances in Engineering Education* 1(3) 1-23, 2009.

7. Burgher, J.K., Finkel, D., Adesope, O., "Comparing Misconseptions in Fluid Mechanics Using Interview Analysis Pre and Post Hands-on Learning Module Treatement." A paper presented to the 2014 Annual Meeting of ASEE.

8. Kaye, N.B. *Teaching Fluid Mechanics: In class activities to enhance student understanding*. [https://teachingfluids.wordpress.com/. Retrieved: Jan. 2015.

9. Mason, J., "Lecture Demonstrations – Fluid Mechanics." *Department of Physics* [http://sci.odu.edu/physics/resources/Demonstrations/Fluid_Dynamics.html?#DynamicFluids. Retrieved: Jan. 2015

10. Matthews, R., Yip, C., Chapman, E., "Physics of Matter Videos." *Physics Demo Videos* [http://physics.wfu.edu/demolabs/demos/avimov/bychptr/chptr4_matter.htm. Retrieved: Jan. 2015

11. SmarterEveryDay ."AK-47 Underwater at 27,450 frames per second (Part 2) - Smarter Every Day 97." [https://www.youtube.com/watch?v=cp5gdUHFGIQ. *YouTube.* YouTube, 22 Jul, 2013. Retrieved: Jan. 2015.

12. White, F.M. *Fluid Mechanics* New York, NY: McGraw Hill, 2009. Print.

13. Sick Science! "Cornstarch Walk on Water - Spangler on The Ellen Show" [https://www.youtube.com/watch?v=RUMX_b_m3Js. *YouTube.* YouTube, 30 Dec, 2008. Retrieved: Jan. 2015.

14. UNM Physics and Astronomy "Laminar Flow." [https://www.youtube.com/watch?v=p08_KlTKP50. *YouTube.* YouTube, 06 Mar, 2007. Retrieved: Jan. 2015.

15. PappyStu, "Hydroelectric Dam Disaster 76 Dead." [https://www.youtube.com/watch?v=SWcdDwECZU0. *YouTube.* YouTube, 06 Mar, 2012. Retrieved: Jan. 2015.

16. MercerReport, “RMR: Rick and Dr. Popsicle.” [https://www.youtube.com/watch?v=UZuZgSQZJ9g. *YouTube.* YouTube, 29 Sep, 2010. Retrieved: Jan. 2015.

17. Fox, R.W., Pritchard, P.J., & McDonald, A.T. *Fox and McDonalds introduction to fluid mechanic,* Hoboken, NJ:Wiley and Sons, Inc. 2011. Print.

18. Bittle, I., “2.3 The Screw Propeller.” *The Ivor Bittle website* [http://www.ivorbittle.co.uk/Articles/Screw%20propellers/Propellers%20for%20net.htm. Retrieved: Jan. 2015.

19. White, F.M. *Fluid Mechanics* New York, NY: McGraw Hill, 2006. Print.

20. G. S. Settles, G. Tremblay, J. M. Cimbala, L. J. Dodson, and J. D Miller, “Teaching fluid mechanics with flow visualization videos,” *Proc. 12th International Symposium on Flow Visualization*, September 10-14, 2006, Göttingen, Germany.

21. “Q: Radial flow between parallel disks (Fig. 3B.10). A part of.” *transtutors.com* [http://www.transtutors.com/questions/radial-flow-between-parallel-disks-fig-3b-10-a-part-of-375097.htm. Retrieved: Jan. 2015.

22. “Pipe Flow Advisor Software” *pipeflow* [http://www.pipeflow.com/pipe-flow-advisor-software. Retrieved: Jan. 2015.

23. Bourg, E., Delage, S., Desoutter, G., “Some Theory.” *INP Toulouse ENSEEIHT* [http://hmf.enseeiht.fr/travaux/CD0203/travaux/optmfn/gpfmho/02-03/grp7/theory.htm. Retrieved: Jan. 2015.

24. Wikipedia Contributors, “Hurricane Fran.” *Wikipedia, The Free Encyclopedia* [http://en.wikipedia.org/w/index.php?title=Hurricane_Fran&oldid=644935410. Retrieved: Jan. 2015.

25. “ZPM cavitation.” *Dryden Aqua Process* [http://www.drydenprocesswater.com/process-water-products/process-water-zpm. Retrieved: Jan. 2015.

26. Peter Bohacek “Direct Measurement Video of a Rotating Water Tank: Purple Hexane and Parabolic Fish.” [https://www.youtube.com/watch?v=f8IwL2ZtDTc. *YouTube.* YouTube, 13 Jul, 2013. Retrieved: Jan. 2015.

27. “Kaplan Turbines.” *Voith* [http://www.voith.com/en/products-services/hydro-power/turbines/kaplan-turbines-560.html. Retrieved: Jan. 2015.

28. x4073 “The Day After (Attack Segment)” [https://www.youtube.com/watch?v=7VG2aJyIFrA. *YouTube.* YouTube, 04 Nov, 2006. Retrieved: Jan. 2015.

29. Kagan, D., “Magnus Effect - "V" Launcher and Ball.” *The University of Iowa* [http://faraday.physics.uiowa.edu/heat/2C20.60.htm. Retrieved: Jan. 2015.

30. Wikipedia Contributors, “Magnus Effect.” *Wikipedia, The Free Encyclopedia* [http://en.wikipedia.org/w/index.php?title=Magnus_effect&oldid=641469616. Retrieved: Jan. 2015.