WATER DAY

An Experiential Lecture for Fluid Mechanics

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Water Day is essentially playtime with water. Different stations are set up outdoors, and the students go from station to station experiencing and observing different basic fluid-flow phenomena. They see how water flows from holes in a tank, how a stream narrows as it falls and how a water stream can knock over a block. These demonstrations are not like the usual laboratory experiments with statistical data analysis; the students make only qualitative observations or rough estimations to get a feel for the phenomena.

Students receive the most benefit from the demonstrations when Water Day is held at the beginning of the semester. Knowing that the students observed the phenomena during Water Day, the instructor can refer to the different stations when the appropriate topic comes up in class. The experiments can be explored quantitatively in class examples or homework problems throughout the semester. For an extra-credit assignment at the end of the semester, the students can be given the original observation sheet with instructions to name the equation or concept that explains the observations seen on Water Day. This forces them to review the course material, which has now been touched upon three different times over about three months.

If the fluid mechanics class is a spring course, Water Day can still be held. Instead of being at the beginning of the semester, it usually occurs at the end of the semester when the weather is warmer. The benefit of being able to refer to the stations throughout the course is lost, but the students' observations can be used to review the entire semester.

I hold Water Day during a regular class lecture for my engineering science "Introductory Fluid Mechanics" course, which is taken by juniors in chemical, mechanical, and petroleum engineering. I encourage student participation with the promise of a perfect homework score for filling out an observation sheet, given to them at the beginning of the demonstration. Although I usually allot an entire lecture to Water Day, it is short enough to be held during half of a 75-minute lecture.

Water Day is held to provide a minimum experience level with fluid flow phenomena. It is especially beneficial for the international students, who make up 10-50% of our fluids enrollment, since many of them are from arid countries and did not have the chance to play with water hoses as children. The demonstrations ensure a minimum experience level for all students, and the course then builds on this experience.

Water Day also incorporates some pedagogical tools. It emphasizes sensing, visual, and active learning styles, which are often neglected in engineering lectures.[1] Holding a Water Day and referring to it during the semester appeals to somatic understanding, which relies on the sense of touch.[2,3] Somatic understanding can be gained by taking an object apart, by feeling the force required to deflect a water stream, and by making the water shoot far with a garden hose. It is the lowest level of understanding, but it gives the students a baseline from which they can develop the higher levels of understanding that we want. Water Day provides an opportunity for somatic understanding, and the rest of the course works takes this understanding to higher levels.

GENERAL PREPARATION

Some assistants and special materials are necessary for holding a Water Day. The campus physical plant can help with hoses and a water supply, and teaching assistants for the class, or other graduate or senior students, can help man the stations. My current Water Day stations cover the continuity, Bernoulli, conservation-of-linear-momentum, and moment-

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of-momentum equations, the *vena contracta* effect, and relative and absolute velocities. The following supplies are needed for these stations:

- *Observation sheets*
- *Nozzles*
- *A tank with holes and plugs*
- *A jug with a hole in the lid*
- *A trash can lid*
- *A book or block*
- *A three-arm spinning sprinkler*

The materials are intentionally common and inexpensive. The experiments are described in detail below, and suggestions for other fluids topics are given later in this paper.

Tank-With-Holes Station • To prepare for this experiment, something must be found to use as a tank. For classroom demonstrations, an 11-oz coffee can is suitable, and for Water Day, a 50-L carboy or a 2-L soda bottle will do well. Punch or drill at least four holes in the tank, keeping the diameter of the hole in proportion to the volume of the tank and making sure there are corks available to plug the holes. Some holes should be at the same horizontal level, and some of them should be at different vertical levels—a five-hole cross pattern works fine. During Water Day, plug the holes and fill the tank. For observation purposes, it is best to have the tank sitting on a cart or table rather than on the ground. Remove the corks and let the students observe the water flow. The observation sheet should direct the students to specifically observe

1. How the water flow from a particular hole changes as the water level in the tank drops *(They should see that the flow from a particular hole shoots a shorter distance from the tank as the water level in the tank drops.)*

Figure 1. *Flow from the vertically-aligned holes in a tank.*

2. How the flows from the horizontal holes are the same or different *(They should see that the water streams from the horizontal holes shoot the same distance from the tank.)*
3. How the flows from the vertical holes are the same or different (see Figure 1) *(They should see that the water shoots further from lower holes than from the upper holes. This is true only if the tank is above a critical height from the ground, which is why the cart or table is useful.)*
4. How the diameter of a jet compares to the diameter of the hole *(They should see that the diameter of the jet is smaller than the diameter of the hole.)*

Observations 1 through 3 can be explained by applying the Bernoulli equation to flow from the surface of the liquid in the tank to the free jet at the hole. Observation 4 is an example of a *vena contracta.* In our course, this material is covered in the fifth week of class when we reach Section 3.6 of the textbook *A Brief Introduction to Fluid Mechanics.*[4]

Variations can be added to the main experiment. Instead of drilling the horizontal holes all the same size, make each one different. The students will be able to see that the jets all shoot the same distance (neglecting viscous effects) but that the flowrates are different. For another variation, try rounding the inside of one of the holes. The students should be able to see the difference in contraction coefficients between the square and the well-rounded holes.

Garden-Hose Station • All that is needed for this station is a garden hose with no nozzle. Ask the students to

1. *Point the opening of the garden hose upward and note how far the water travels above the opening*
2. *Cover part of the opening with a thumb and note how far the water travels above the opening (see Figure 2, next page)*
3. *Experiment with covering the opening and noting the different distance the water travels.*

The students should be able to see that the water travels further when more of the opening is covered. This can be explained by assuming constant flowrate and applying both the continuity and Bernoulli equations. This problem is also addressed in the fifth week of our course and is covered explicitly in Problem 8.24 of the text.[4] For a variation of this station, include a flowmeter and consider the assumption of constant flowrate.

Jug Station • For this station, a jug with a hole in the lid is needed—a one-gallon milk jug works well. Make a quarter-inch or smaller diameter hole in the lid (inserting a short section of a straw in the hole helps make the jet smoother), fill the jug with water, and turn it upside down, as shown in Figure 3. As the water drains from the jug, the students can observe the diameter of the jet as a function of the distance from the jug. The diameter of the jet should decrease as the stream moves further from the jug. This can be explained by

applying the continuity and Bernoulli equations to two points in the jet. This material is covered at the same time as in the previous two stations and in Problem 3.24 of the textbook.[4] A variation of this station suggested by a reviewer is to change the viscosity of the water by adding sugar. At high viscosities, the flow should be slower and smoother.

Trash-Can-Lid Station • For this station, an assistant, a trash-can lid, and a garden hose with a nozzle are needed. The student should hold the trash can lid perpendicular to the ground at all times and should be about 10 feet from the assistant. Using a nozzle, the assistant should form a narrow stream of water and aim it at the trash can lid (see Figure 4). The student holding the lid should be directed to observe the forces required to hold the lid in place as he moves the lid from perpendicular to the water stream to nearly parallel to the water stream. It seems to be easier to feel the difference in forces if the lid is kept perpendicular to the ground at all times (see Figure 5). The student should notice that more force is required to hold the lid in place when it is perpendicular to the water stream than when it is parallel. This can be explained by applying the conservation of linear momentum equation to the water stream. This material is covered in the eighth week of the course when we reach Section 5.2 of the text.[4] Problem 3.40 in *Fluid Mechanics*[5] addresses the perpendicular part of this station. A second part on the nearly parallel case could be added.

Book-or-Block Station • A book or block, a garden hose, and a nozzle are needed for this station. If a book is used (telling the students it is their fluid mechanics book is particularly effective at the end of the semester), wrap it well in plastic bags so it doesn't get wet. Place the book or block vertically on its short side and adjust the nozzle to a narrow jet of water. Direct the students to observe what happens when they aim the jet at the book, starting at the bottom of the book and moving to the top. Nothing should happen when the stream is at the bottom, but the book will tip over as the stream is moved upward. This can be explained by applying the conservation of linear momentum equation to the water stream to find the force of the book on the water. This force is turned around to find the force of water on the book, and a moment balance is done on the book. This station is considered explicitly in Problem 5.30 of the text.[4] An interesting variation would be to knock over books of the same thickness but different weights or blocks of the same size but different densities.

Figure 2. *Water shooting from a garden hose with the opening partially covered.*

Three-Arm-Spinning-Sprinkler Station

For this station, a two- or three-arm spinning sprinkler is needed. Connect it to the garden hose and instruct the students to determine which direction the nozzles point (clockwise or counterclockwise), which direction the sprinkler rotates (clockwise or counterclockwise) when the water is turned on, and the absolute and relative velocities of the water jets. The students should be able to determine that the sprinkler rotates opposite to the direction

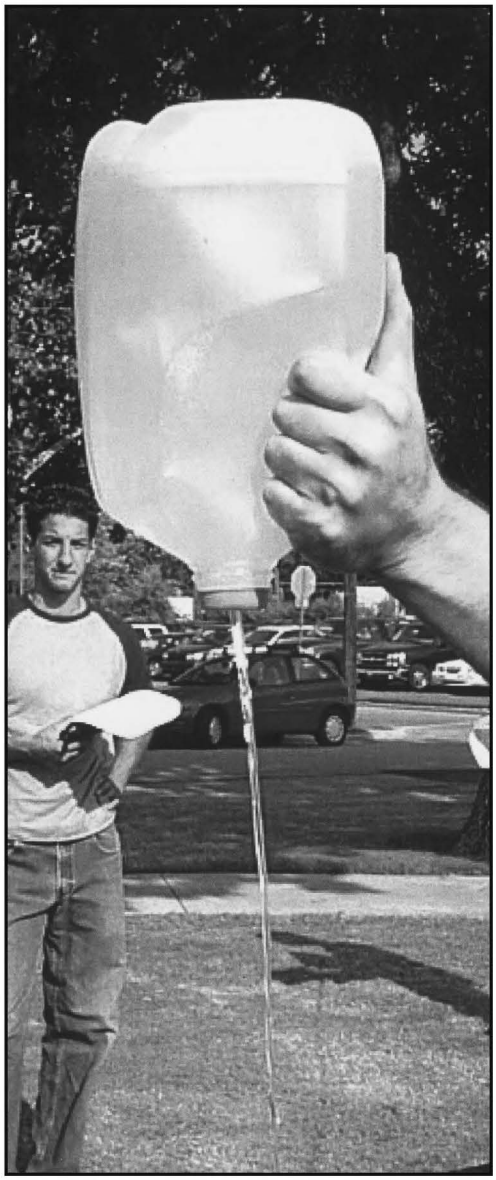

Figure 3. *Water flowing from an upside-down jug.*

the nozzles point and that the relative velocity (relative to the sprinkler) is normal to the nozzle exit area. They probably will not be able to determine that the absolute velocity (relative to a fixed frame of reference) is radial if the resisting torque is negligible. This can be explained by the moment-of-momentum equation, covered in the seventh and eighth weeks of the course, in Sections 5.1.3 and 5.2.4 of the text.[4] A variation would be to add a flowmeter and observe the rotation rate as a function of water flowrate.

Other Stations

Adding pressure gauges at various locations in the hoses could demonstrate pressure drop due to fittings and friction. Other stations suggested by reviewers are observation of delta formation in a muddy or sandy parking lot, the location of eddies in a creek relative to flow disturbances, and vortex formation in a draining tub. With latex paint and a paint gun, they could see the effects of viscosity and particulates on fluid flow. Anything new the students can see or feel will help their understanding of the material later. The challenge in developing new stations is keeping them simple, safe, and inexpensive.

Figure 4. *Trash-can-lid station. Note that the student is tipping the lid towards the ground instead of keeping it perpendicular to the ground.*

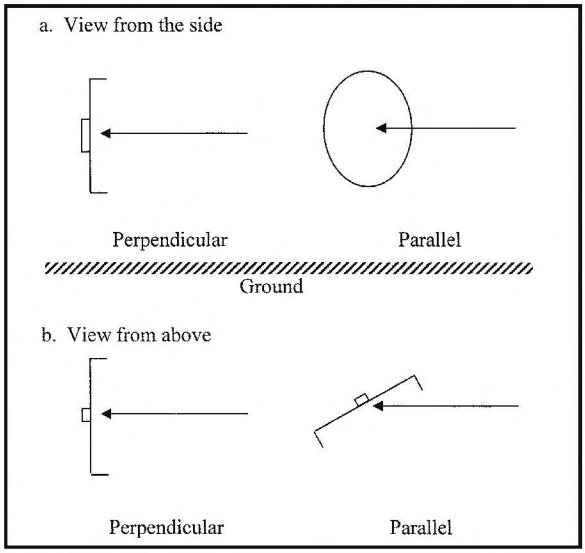

Figure 5. *Sketches of the trash can lid in positions perpendicular and parallel to the stream. Note that the plane of the lid remains perpendicular to the ground at all times.*

OTHER APPLICATIONS OF WATER DAY

Water Day can be used with groups other than fluid mechanics classes. The idea for Water Day came from Dr. Christi Luks, who had done similar experiments with middle-school students at a Young Scholars Program and Engineering Summer Academy. Water Day could be used in an Open House or done when recruiting prospective freshmen. The stations could also be used with a freshman introduction-to-engineering class to whet their appetites for things they will understand later. Some of the stations are easily modified for use indoors, which expands their range of usefulness.

EVALUATION

One of the pedagogical goals of Water Day is to include sensing, visual, and active learning in a lecture course that might not include them otherwise. Sensing is used in the trash-can-lid station when the students feel the difference in force, and visual learning is in all the stations. This watching is not "mindless" since the students must evaluate what they see and record their evaluations on an observation sheet (*e.g.*, they note that the stream narrows as it falls from the water jug). Active learning is included in the trash-can-lid and water-hose stations because the students must do something. Taken together, the stations add sensing, visual, and active learning to the course.

Another pedagogical goal is to provide an opportunity for somatic understanding as a baseline to build upon. Water day *is* experiencing fluid flow phenomena, so students leave with a minimum level of somatic understanding.

No formal assessment of Water Day has been done. Nearly 100% of the students participate since they are encouraged by the promised homework score. Informal feedback indicates that the students enjoy it. One comment from a group doing this at the end of a semester was, "Cool! You can see the *vena contracta!*" One student said that he liked having the experience to draw on later, *i.e.*, he liked having the somatic understanding to build on.

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