TWO “TAKE HOME” EXPERIMENTS IN FLUID MECHANICS

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I. Introduction

As pointed out by Scott[1] and others, the background of most engineering students contains little experience in observing the world around them. When we introduce basic concepts using simple devices such as pistons and cylinders, springs, boiling water, etc., there are a large number of students who have not “seen” such devices and processes. Creating a connection between the analytical models and the real devices they apply to is thus becoming increasingly difficult.

To spend precious and limited time in class on the examination of simple physical devices greatly reduces the time available for the development of fundamental laws and analytical techniques. When we try to conduct such exercises in laboratory activities, we often find that the time required for students to carry out the mechanical operations necessary to run the experiment are considerable. Since most students have not handled tools, simple tasks such as assembling apparatus, wiring up meters, etc. can consume much of the time and require considerable instructor intervention.

Consider an experiment in which the student is expected to verify the pressure-temperature relation for boiling water in a flask attached to a vacuum pump. If a student group is required to connect the pump, thermocouple, and vacuum gauge along with some tubing and valves and then vary the pressure by manipulating the pump and valves, this activity can take up most of the time. At the end of the exercise, the student will have a list of “things” that they “learned” from the experiment which looks like this:

a. What a vacuum pump is
b. How to connect tubing and valves
c. How to adjust valves to get a set of test values
d. What vacuum means and how to convert vacuum to absolute pressure
e. Something about graphing pressure vs. temperature

So that the objective we wanted to get is buried in a list of other things. What should have been a simple 2 hour activity would require three 2 hour sessions so that we can separate the mechanics of running the experiment from the thermodynamic objective. It is no wonder that many have turned to demonstrations in which the instructor or a technician takes care of the mechanics of running the test or to computer simulations.

II. The "take home" concept

One way to overcome the limited class time is to send students home with simple equipment or with instructions on how to use materials found around the apartment or dorm to construct the test rig. Now the experiment becomes equivalent to a homework assignment and students are more willing to invest time in the activity. This is especially true if the experiment can be made novel.

The danger in using these kinds of exercises is that the student has no instructor present. This means that we must design the experiment so that the probability of mistakes in constructing and running the apparatus is very low. The key to success here is to make the device very simple and to encourage students to work with each other.

This restriction to simple devices may seem at first to be very limiting. We certainly cannot conduct complex or highly precise exercises under these limits. First however, we must remember that the examination of the simplest physical processes is the first step in one's search for understanding. Indeed, it is precisely these kinds of devices (pistons and cylinders, springs, pushing blocks uphill, etc.) that are used in elementary textbooks to introduce the study of engineering principles. The fact we often fail to recognize is that most students have not noticed such devices at all! This is in spite of the fact than many middle and secondary school science programs use precisely these kinds of simple devices. Yet many students seem to have failed to benefit from the exposure.

Secondly, a little thought will illuminate a great many simple devices that we can use for initiating this "curiosity" phase of learning. A simple list of items used by students in everyday life provides a host of candidates for study and an equal number of candidates for instruments which, thanks to our affluence, are available to all at very low cost. Virtually every student has or can easily obtain digital fever thermometers, watches with stopwatch capability, hair driers, thermos bottles, and all variety of plastic containers and other equipment for a take home experiment.

III. Take home experiments at the University of Virginia

The two simple experiments in this paper are part of the fluid mechanics laboratory course in the Department of Mechanical and Aerospace Engineering at the University of Virginia. This is a 1 credit hour attachment to the 3 credit fluid mechanics course given in the sophomore year. It involves a 2 hour formal laboratory with some outside work required. Based on a "2 hours at home for every hour in class" philosophy, we can expect the average student to invest 4 hours of time after the lab for the completion of a report or the carrying out of one of these "take home" exercises. Based on the success of these and similar exercises in this course, we are working to create additional materials of this nature for other courses.

There are many different objectives that one may entertain with these and similar exercises. In our case we seek first to illustrate some fundamental concepts such as hydrostatics and the Bernoulli equation. Secondly, by having students use these instruments on common materials and systems at their disposal, they begin to see how the physical world operates.

For example, they may discover that oil is less dense than water, that soda and other solutions are mostly water, and learn why the top of a convertible balloons out when driving at high speeds. These are all valuable "experience factors" which need reinforcement.

There are additional opportunities such as the illustration of experimental uncertainty. However, it is not the intent of this paper to suggest specific uses and cover issues of pedagogy in detail. The purpose is more to make the reader aware of the idea of a take home experiment and encourage its use.

It is also difficult to make general statements about how effective such experiments are. Proper limiting of objectives and careful instructor-led discussions before and after the exercise are as critical to success as the particular equipment and procedure. In the hands of some instructors, these exercises can have little impact. Further, unless there is reinforcement of the idea in more than one course, the benefits may be lost.

IV. The hydrometer experiment

In this experiment, each student is given a bag containing a straight drinking straw, a small rubber stopper for the end, and 7 BBs. These are easily obtained from local stores and scientific suppliers. The basic equation of hydrostatics is developed in the lecture course and the specific application to the hydrometer is illustrated in the laboratory "manual".

Students are then given a precision balance with which to determine the mass of the straw, stopper, and BBs. They also measure the diameter of the straw with a micrometer. They then go home to calibrate the hydrometer in water and then use it to measure the specific gravity of at least three other fluids of their choice.

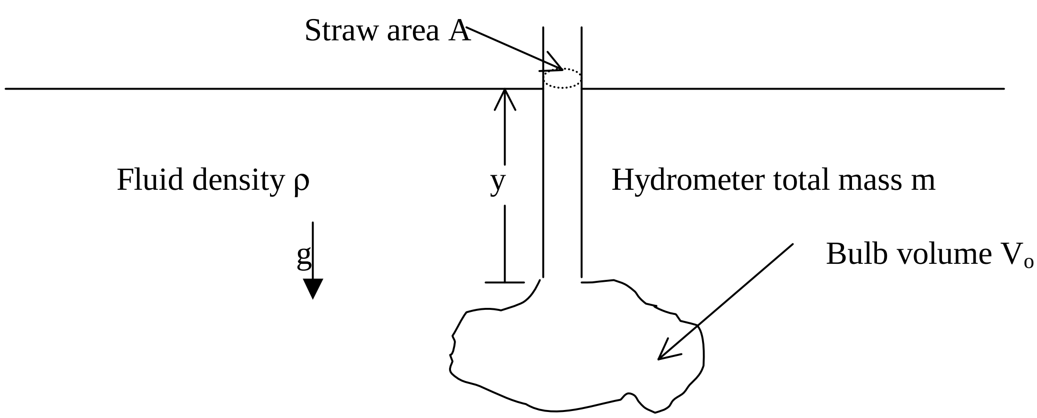

FIG. 1: Hydrometer Nomenclature

The basic equation for the hydrometer that is developed in the lab discussion is:

$$\rho = \frac{m}{V_o + Ay} \qquad (1)$$

If we use water with density ρ_w as the calibrating fluid and assign y=0 to the stem marker location when the instrument is immersed in water, then we may solve (1) for V_o and obtain:

$$\rho = \frac{m}{m/\rho_w + Ay} \tag{2}$$

where now "y" is the distance along the stem from a mark made on it when the instrument is immersed in water. From this we can determine the specific gravity of another fluid:

$$s.g. = \frac{\rho}{\rho_w} = \frac{m/\rho_w}{m/\rho_w + Ay} = \frac{1}{1 + \frac{\rho_w}{m} Ay} \tag{3}$$

and the sensitivity of the instrument is:

$$\left| \frac{\partial y}{\partial s.g.} \right| = \frac{m/\rho_w}{A[s.g.]^2} \tag{4}$$

The students select the number of BBs to use (between 3 and 5) so that the hydrometer floats in water. Then a mark is made on the stem at this condition. The difference between this mark and the interface with another fluid is "y" from which equation (3) gives the specific gravity.

The fluids selected most often by students were cooking oil (50%), dish soap (30%), rubbing alcohol (20%). Reported values of specific gravity for cooking oil ranged from 0.84 to 0.93, for dish soap, 0.96 to 1.1, and for rubbing alcohol, 0.8 to 0.9 Considering that the sensitivity of the device ranges from 7 to 16 cm per unit specific gravity, a measurement error of 0.5cm gives an error of about 0.05 in specific gravity. 0.5cm reading error is about what we would expect and reported specific gravity values are close enough to ±0.05 to indicate success. While the objective of the experiment is not to produce extremely accurate specific gravity values, it is clear that the instrument is sufficiently accurate for its intended purpose.

V. The manometer experiment

In this experiment, each student receives a 1.5 meter length of Tygon tubing. The student then tapes the tubing to a ruler to construct a simple U-tube manometer which is installed in an automobile by sticking one end outside an almost closed window under the roof rail and leaving the other end inside the car as illustrated here.

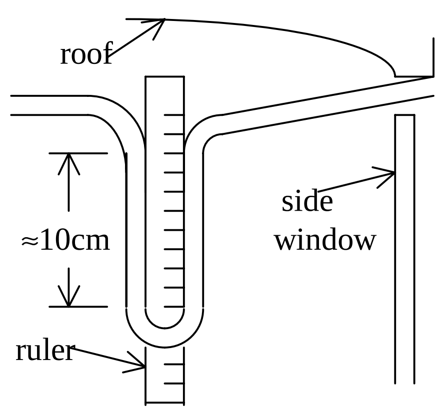

FIG. 2: Manometer Installation

The basic equation for the manometer is given in the lecture course and text and so no discussion of the theory is required in the lab. There are also no precision measurements required before the student goes “on the road” with the instrument. We do, however, insist that the students work in pairs so that one can operate the equipment while the other drives. There is also a reminder to stay within the speed limit!

In the laboratory before sending the students home, we conduct several experiments using various precision manometers such as measuring the pressure rise across a fan. Having seen what a manometer is used for, the manual for the take-home part concentrates on discovering things about their car using the manometer as a tool as opposed to study of the manometer itself.

First, we present a diagram showing the pressure distribution over a car (which one can find in many references such as Gillespie[2]) and discuss the pressure coefficient. The students are instructed to measure the pressure difference between inside and outside the car and plot this pressure difference vs. car speed on log-log paper. The results fall along a straight line with a slope of 2 quite nicely. Students also discover that the pressure inside the car is greater than that outside the window and see why a convertible top balloons out when driving at high speed.

Second, we illustrate the simplified layout of a typical automotive heating/air conditioning system shown below.

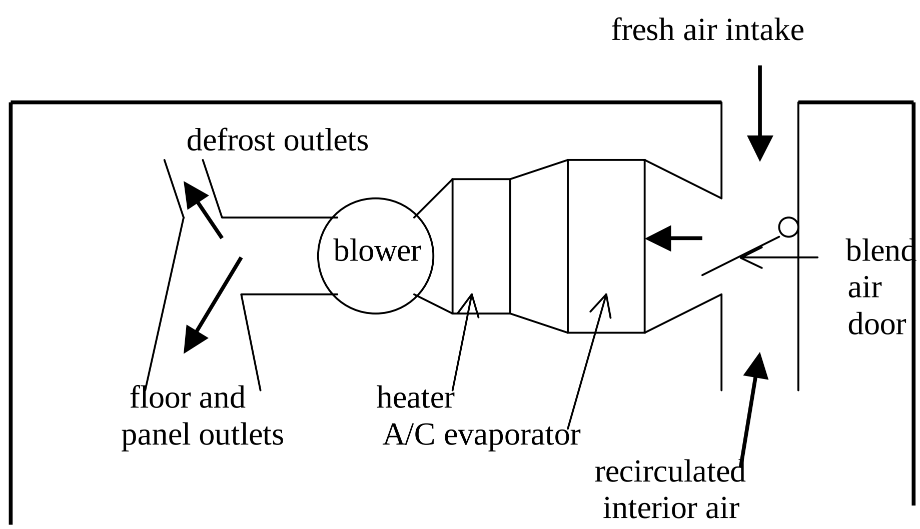

FIG. 3: Simplified Diagram of Automotive Heating/A.C. Package

In the heater mode, the blend air door blocks all recirculation of interior air so that only fresh air is taken in for heating. This is also the mode of operation in the “normal” A/C setting. In the “Max. A/C” setting, the blend air door shuts off fresh air and recirculates interior air.

Students can then verify this by selecting heat or A/C with the car stationary and noting whether the interior pressure is greater than the outside air pressure. The manometer thus serves as an aid in understanding the operation of this system. We find that most students are curious about how their car operates and appreciate this “real world” exploration.

VI. Student response

The hydrometer experiment provides a vehicle for evaluation of the student's grasp of its operation and general knowledge about the specific gravity of various fluids. So we will provide a brief discussion of our results after several years of running this exercise.

A general understanding of the subject of hydrostatics can be tested by asking questions about how the hydrometer will behave in various situations. This understanding can be tested with a simple quiz such as the one below. The quiz also asks for input on the value of the home exercise as a learning aid.

The questions may be categorized roughly as testing understanding of the principles (2,3,4,5,6,7) and testing for practical information retrieval (8,10,11).

The quiz was given to the 44 students in the class one month after the completion of the home experiment. This hopefully reduced the number of answers to the "understanding" part that would be based on memorization of the answers in preparation for the general graded exam on the subject that was given a few weeks before. Since there is no overall final exam in the course, students would not have to remember this material for an end of course final exam.

The numbers in [ ] indicate the percentage of the students who got the answer right or, in the case of question (9), the percentage who answered "yes". While it is difficult to establish what "score" is representative of successful learning, these results are encouraging.

HYDROSTATICS GENERAL KNOWLEDGE QUIZ

1. What was the most difficult part of the take home hydrometer experiment for you?
2. [77% correct] Will a hydrometer give correct readings if used on the moon where the gravity is less than that on Earth?
3. [77% correct] Will a hydrometer, placed in a bucket of fluid that is being swung around in a circle give correct readings?
4. [82% correct] Will a hydrometer sink deeper into a fluid with a larger specific gravity or will it rise higher?
5. [88% correct] The hydrometer is in equilibrium when what two forces are in balance?
6. [91% correct] If properly calibrated, will a hydrometer work when the fluid above it is not air but another liquid?
7. [75% correct] When two liquids that do not mix and of specific gravities 0.8 and 1.1 are placed in a container, which fluid will be on the top?
8. [39% correct] What are the units of specific gravity?
9. [55% said yes] Was the take home hydrometer experiment a significant aid in helping you understand hydrostatics? (don't just say yes to make me happy!)
10. [100% correct] Is the specific gravity of oil less than or greater than that of water?
11. The range of specific gravities of typical fluids is which of these
    a.[60%] 0.5 to 1.2 b.[10%] 0 to 1 c.[10%] 0 to 10
    d.[2%] 0 to infinity e.[18%] 0.9 to 1 f.[0%] 80 to 100 g.[0%] 50 to 200

It came as a surprise that only 55% said the home exercise was helpful. Scoring of the quiz with 10 pts off for each wrong answer to questions 2,3,4,5,6,7,8,10,and 11 showed that the average score of those who thought the home exercise was helpful was 82% while the average score of those who through the home exercise as not helpful was 78%. This does not indicate a significant improvement for those who thought the exercise was helpful. However, it is interesting to note that only one of those who did not think the exercise was helpful got 100% while four of those who did think the exercise was helpful got 100%. The question remains as to whether those who liked the exercise would have done as well had they not experienced it.

It turns out the whether the student got correct results on the take home experiment or not is an indicator also. The causes of incorrect results are by far the failure of the student to follow directions or the making of simple mistakes. Of the 44 students who did this experiment:

4 got specific gravities much different from 1 for items that are primarily water
8 reported specific gravities less than 0.5 or greater than 2
3 reported specific gravities like 87 or 98
8 gave wrong answers for the sensitivity of the device.

By examining the calculations, it was obvious that the 8 wrong answers for the sensitivity were, in 7 cases, due to the use of the wrong units for the cross sectional area of the straw or a simple mistake in calculating it from the known straw diameter. The incorrect specific gravity values were the result of similar mistakes. This supports the view that students do not spend sufficient time and care in their approach to problems as reported by Woods[3] and others.

The more telling fact is that the students who got specific gravities significantly different from 1 either did not realize that most liquids have specific gravities between 0.7 and 1.2 or simply did not bother to look at their results and think critically about them. This “mistake” is less an indicator of their understanding of hydrostatics than it is an indicator of their “common sense” knowledge base.

A follow-up discussion of the student results is critically essential here because both of these errors: simple calculation mistakes and failure to critique their own results, are crucial elements of good engineering. If such a critique is carried out in, say, a class discussion, the fact that the students spend more time on the actual physical device at home than they would have had time for in a laboratory period is of great benefit. In addition, it gives us the opportunity to stress care in calculations, critical thinking about the results, and the value of “common sense” knowledge.

VII. Conclusions

It is important to point out that the success of such exercises is very much a function of they way the project is presented. Most students are “direction followers” and seek to do what they believe they are to be graded on. This means that the written and lecture materials accompanying the experiment need to stress the objective and clearly state what the student is to look for. One must also provide “idiot proof” instructions for construction and use of the device since failures here tend to discourage the student who then dismisses the activity as just another exercise to complete. Too often this leads to copying someone else’s result and little additional learning.

The enthusiasm of the instructor will also play a role in motivating the student to look beyond the mechanical tasks of carrying out the work. It is very difficult to motivate students to look further unless the entire course reinforces this idea of observing and thinking. It is even more difficult if other instructors are not doing the same. Unfortunately, with increasing numbers of students having never been interested observers, the percentage of the class that sees activities like this as a learning opportunity is depressingly small. These factors make any significant improvements in education through the use of this kind of experience a strong function of the climate that exists at a particular school.

In summary, the requirements for a good “take home” experiment are:

1. It must be so well described that every student can carry out the mechanics of building and using it without frustration.
2. It must involve simple materials that are either provided or easy for students to obtain.
3. Recognizing the many students will require much more time to assemble the equipment than we estimate, the amount of work to be done must be limited.
4. The objectives should be few and clearly stated.
5. There must be carefully crafted questions
6. The results need to be critiqued
7. The experiment must be altered over several trials to eliminate difficult parts.
8. The experiment must be attached to a lecture course and run at the proper time.

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