

# **Design, Building and Teaching with a Hydrostatic and Buoyancy Apparatus**

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## **ABSTRACT**

A typical Fluid Mechanics laboratory includes various laboratory equipment and instruments to cover standard topics. However laboratories may not include a hydrostatic device, assuming it is so straight forward that it does not warrant a laboratory instrument or a laboratory exercise. As part of the senior design class a group of students wanted to design and build a Fluid Statics device that will clearly verify the static force and buoyancy theories of fluids. An idea from the Internet was used to design such a device. It was then built and tested for measuring fluid static force and buoyancy. The device worked pretty satisfactorily and the authors decided to include it as a regular laboratory experiment in the Fluid Mechanics course. The students were able to use the device easily to verify the hydrostatic pressure and buoyancy theories within a respectable margin of error. Student learning and satisfaction were measured by specifically designed survey instruments which indicate good comprehension of the topics. Some dissatisfaction with the accuracy and repeatability of measurements were indicated by the students. These would be the target for improvement in the next version of the apparatus. This paper describes the design and operation of the device as well as teaching modules and user surveys to match the results with laboratory outcomes. Such an inexpensive but functional apparatus can enhance a traditional undergraduate fluids laboratory. Student learning was positive after using it for a laboratory exercise. Included drawings and teaching modules may benefit other faculty members who want to take advantage of the current design.

Keywords: Fluid mechanics, fluid statics, hydrostatic, buoyancy, laboratory, design.

## **INTRODUCTION**

The senior machine design class includes capstone design projects done by teams of students. These students had already taken the Fluid Mechanics laboratory class where the need for a hydrostatic pressure measurement system was mentioned. The students were asked to come with such a device. Although many sophisticated pressure measuring instruments already available, a simple fundamental measuring device was desired, that did not rely on power, sensors, computers etc. One group of students discovered the current design online and was allowed to undertake a redesign and building project of the apparatus. The objective of the design project was thus to design and building a prototype equipment that can demonstrate the hydrostatic principle as well as buoyancy principle.

## **DESIGN AND BUILDING OF THE APPARATUS**

The design problem was described by a design statement: "Design and build a prototype equipment to demonstrate the hydrostatics and buoyancy principles of fluids at rest without use of sensors and complex data acquisition or electronics."

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Further customer requirements included:

1. The equipment will be simple to operate.
2. It will be a table top model easily convertible from hydrostatic to buoyancy setup.
3. The system will be sufficiently accurate and repeatable.
4. Set up and experiment can be completed within 1 lab period.
5. Good repeatability of results.
6. It will not be too expensive.
7. It will be safe to operate.

Design specifications to satisfy the customer requirements:

1. Use a submersible pump and dead weights to balance buoyant force.
2. Overall dimensions will not exceed 30 inches cube.
3. Accuracy < +/- 5% force
4. The set up time <30 min. Experiment time <2 hours.
5. Results are within 5% between experiments
6. Total cost <\$100.
7. Minimum chance of electrical shock or water spill.

Bill of Materials:

1. 2 Plastic water tanks, one for hydrostatic pressure measurement using the quarter tube element, the other for buoyancy experiment using the test piece.
2. Cross bar to support the hinged horizontal support bar.
3. Horizontal support bar
4. Balance weight to counter balance the quarter tube in air such that its sealed face is vertical
5. Ball bearing to hinge the horizontal support bar from cross bar
6. Submersed water pump (aquarium grade)
7. Plastic tubing to transfer water from Hydrostatic tank to buoyancy tank.

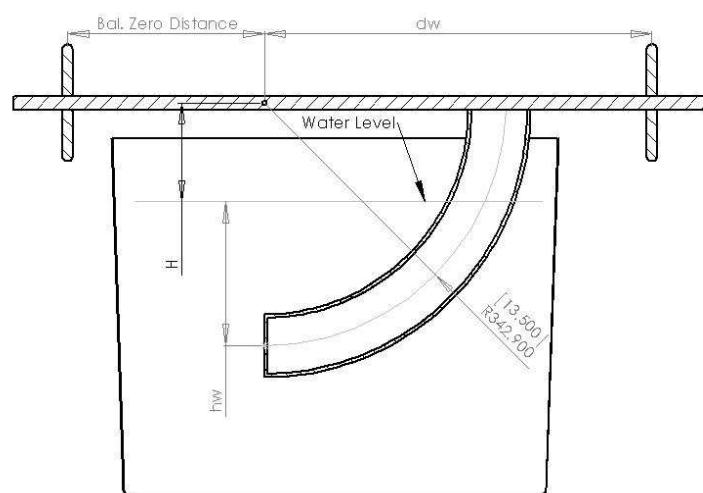


Figure 1: Sketch of the tank assembly.  $h_w$  is the depth of water to the center of the tube face and  $H$  is the distance from the hinge to the water surface.  $d_w$  is the distance from hinge to counter weight.

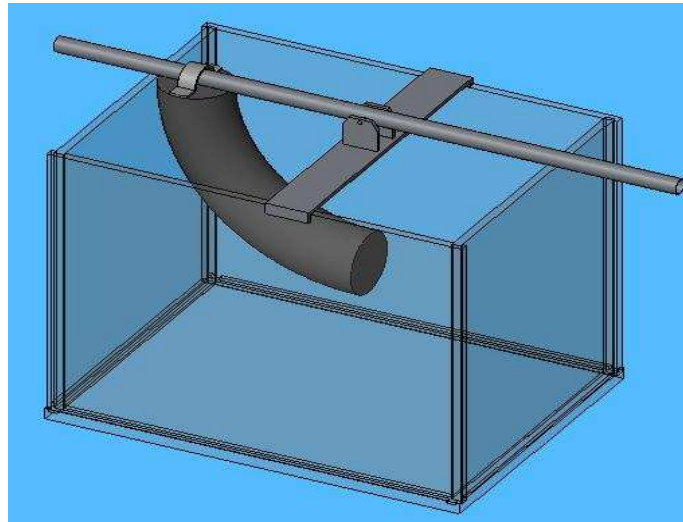


Figure 2: 3-D rendering of the quarter circular tube assembly and support hinge..

#### Assembly:

The system consists of 2 identical tanks with one tank of water. Water is transferred from one tank to the other when the experiment is switched from hydrostatic pressure to buoyancy experiment. This way water is conserved. Figures 1 and 2 show the assembly. Each tank has its own cross bar to accept either the quarter circular tube subassembly or the spring scale and buoyancy test piece.

#### HYDROSTATIC PRESSURE EXPERIMENT

The tank is set up with the quarter circular tube assembly as shown in Figure 2. The assembly is balanced using counter weights before water is introduced, as shown at the left end of the horizontal bar. Once the water is introduced the hydrostatic pressure and the resulting force on the face of the tube will tend to swing the tubing counterclockwise, as shown in Figure 2. Then it is brought to equilibrium (horizontal) position by applying and positioning ( $d_w$ ) the weights ( $F_w$ ). Different level ( $h_w$ ) of water will generate different magnitudes of force, demonstrating the principle of hydrostatics. The water surface is at a distance of  $H$  from the hinge and the depth of water from surface to the center of of the circular face of the tubing is  $h_w$ . The hydrostatic force  $F_b$  acts on the tubing face at a distance  $H+h_w$ . The balancing weight  $F_w$  acts at a distance of  $d_w$  from the hinge. When balance is achieved, the moments created by hydrostatic force and the balancing weight will balance each other. Thus :  $F_h*(H+h_w) = F_w*d_w$ . One can calculate the hydrostatic force as:

$F_h = F_w*d_w/(H+h_w)$ . On the other hand the hydrostatic force can be calculated using the formula  $F_h = \gamma*h_w*A$ ,  $\gamma$  being the density of water at room temperature and  $A$  is the area of the face of the tubing. These two values of the  $F_h$  is compared as a measure of accuracy of results obtained by hydrostatic experiment. The error of ther experiment ranged from

6% to 14%, which are high. The difficulty of accurately measuring the distances to the surface and center of the face of tubing is considered as main contributor to this error.

### BUOYANCY EXPERIMENT

The buoyancy test piece was hanged in the tank with no water in it. The test piece's weight in air was recorded. Then the water was admitted to submerge the test piece completely. While under water, the test piece seems to have lost some weight that is due to the buoyancy force on the test piece by the water in the tank. The weight of the displaced water will be the buoyancy force acting to force the test piece upward. On the other hand the volume of the displaced water will be the same as the volume of the test piece. Knowing the density of water at room temperature and the buoyancy force, the volume of the test piece will be found. Then this experimental volume calculation will be compared with the volume of the test calculated from its geometry. The error in measuring volume of the test piece using buoyancy experiment was around 8%. Again the accuracy of measuring the physical dimension, buoyancy of the wire and irregular hole dimensions, as well as resolution of the electronic scale were large contributors to this error.

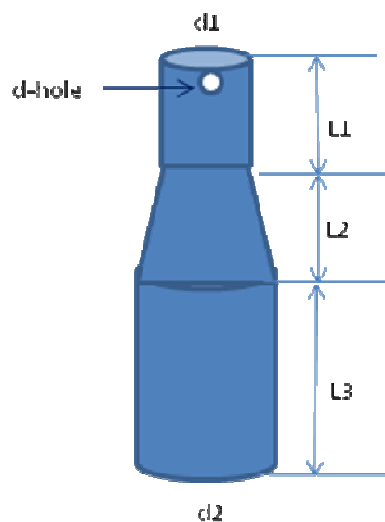


Figure 3: The buoyancy test piece.  $L_1=21$  mm,  $L_2=29$  mm,  $L_3=41$  mm.  $d_1=20$  mm,  $d_2=29$  mm,  $d_{\text{hole}}=4$  mm.

### USABILITY ASSESSMENT

A survey was conducted past semester among 2 sections of Fluid Mechanics Laboratory students, totaling 20 respondents. The survey was a simple one intended to get feedback on basic usability data for the equipment and of course how this equipment contributed to strengthen the fundamental concepts of fluid statics.

There were just 5 topics in the survey which are listed in Table 1. Students were asked to grade each topic between 1 and 5, 5 being excellent and 1 being unsatisfactory.

Table 1: List of usability assessment questions

1	Equipment demonstrates important fluid mechanics principles
2	Equipment operation is understandable
3	Equipment provides acceptable accuracy of data
4	Equipment is reliable
5	Your results were useful in improving your knowledge of fluid statics

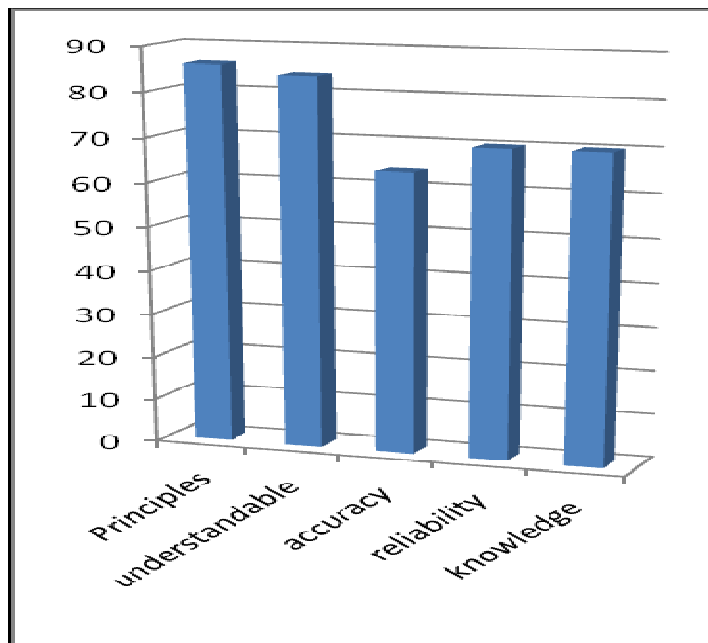


Figure 4: Weighted summary of satisfaction survey results by category.

The results in Figure 5 show most satisfaction with topic #1 (86%) and #2 (84%), while least satisfaction was #3 (64%), “Equipment provides acceptable accuracy of data.” Maximum score could be 100, calculated by multiplying number of students (20) by maximum score (5). This poor score was expected as accuracy of measuring the output data, such as depth of center of face under water, was poor. Only eye estimate was used to measure underwater depth using a ruler. It was inherently very unreliable and not repeatable. These results have prompted the

authors to consider redesigning the depth measurement method. Furthermore, the buoyancy experiment relied on a spring scale for measuring buoyant force. The spring scale had serious repeatability problem especially at low loads, such as our buoyancy specimen. A larger object is planned for next semester, to minimize the scale % error. There were few other observations by the instructors such as instability of the counterbalance, lack of control as to how far the dead weights positioned for equilibrium etc. These are also on the upgrade list for the equipment.

## **CONCLUSION**

A senior student team designed and built a hydrostatic pressure and static buoyancy test apparatus for use in the Fluid Mechanics laboratory by the students. Despite serious problem with accuracy and consistency of data acquired, the equipment functioned to overall satisfaction of the author instructor. A survey of fluid lab students revealed enhancement of understanding of the hydrostatics in general as a result of the lab exercises. Lessons learned regarding accuracy and inconsistency of the result has prompted the authors to start redesigning of the equipment. The original design team was very satisfied that their product is being made a part of the laboratory. The experimental set up need to be upgraded to alleviate the known problems. This project has been subject of pride and satisfaction for the design team members. The satisfaction of a successful design project enabled the design team to overlook the hard work and long hours in the shops to complete the project. The design team was unintended beneficiary of the Fluid Statics knowledge, by way of designing the equipment.

## **ACKNOWLEDGEMENTS**

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