Lab 10. Buoyancy

Goals

• To experimentally determine the relationship between the buoyant force on an object that displaces a known weight of water.

• To compare the buoyant behavior of an object more dense than water with that of an object less dense than water.

• To calculate the densities of aluminum and wood cylinders from your data and to compare these densities to handbook values.

Introduction

Buoyancy is the name given to the force that arises when an object displaces a fluid (either a gas or a liquid) in a force field (usually gravity). The buoyant force is responsible for keeping ships from sinking and for keeping hot air balloons in flight. If an object is at rest in or on a fluid, it experiences a net force of zero. The forces acting on a partially or completely submerged object at rest generally include the gravitational force, $F_g$, the buoyant force, $F_{\text{Buoyant}}$, and whatever additional force (if any) is required to hold the object in position. In the work below, this holding force is supplied by and measured with a force sensor. When the object is at rest,

$$F_{\text{Sensor}} + F_g + F_{\text{Buoyant}} = 0 \quad (10.1)$$

In this lab, you will measure the buoyant forces acting on two cylinders as they are submerged in water, and relate these forces to the weight of the water they displace. You will also calculate the average densities of each cylinder. The cylinders are marked at centimeter intervals along their lengths. The cylinders are lowered into a beaker with their long axes perpendicular to the water surface, so the volume submerged, $V_s$, is

$$V_s = \pi R^2 L_s = AL_s \quad (10.2)$$

where $L_s$ is the length of the submerged portion of cylinder, $R$ is the cylinder radius, and $A$ is the cylinder’s cross-sectional area. The weight of the water displaced by the object is given by
CHAPTER 10. BUOYANCY

\[ W_s = \rho_w V_s g \]  

(10.3)

where \( \rho_w \) is the density of water \((1.000 \times 10^3 \text{ kg/m}^3)\).

**Buoyant force on an object more dense than water**

Before beginning, draw a free-body diagram showing the forces on an object (more dense than water) partially submerged in water.

If you have questions on how to set up the force sensor, refer to the Force Sensor section of the Computer Tools Supplement at the back of the lab manual. The force sensor uses one of the analog input channels (A, B, or C) on the interface unit.

Carefully hang the aluminum cylinder on the force sensor. With the lab jack near its maximum height, adjust the position of the force sensor so that the cylinder sits completely inside the tall beaker without bumping the sides. Then add water to the beaker until the aluminum cylinder is completely submerged. This ensures that the beaker has enough water to cover the cylinder, but is not so full that water will spill when the cylinder is immersed. Use water from the sink at the back of your lab.

To begin the experiment, lower the lab jack so that the aluminum cylinder is completely out of the water. With the aluminum cylinder hanging in the air, tare the force sensor. This sets the force sensor reading to zero with the entire weight of the cylinder applied. The force sensor reading as the cylinder is immersed will then equal the change in force, that is, the upward buoyant force. Since the force sensor in this orientation reads positive for upward forces, the upward buoyant force will be sensed directly as a positive force.

Now vary \( L_s \), the length of the cylinder that is submerged (in 1-cm increments), measuring the buoyant force for each increment, until the cylinder is completely submerged. Try to complete these measurements within about five minutes. This minimizes the effect of sensor drift on the force readings.

Make a graph that compares the buoyant force (on the \( y \)-axis) with the weight of the water displaced (on the \( x \)-axis) for each value of \( L_s \). From the graph, can you deduce a simple mathematical relationship between the two? Discuss/Explain. Look up Archimedes’ Principle in a textbook. Do your results support the validity of Archimedes’ Principle?

**Buoyant force on an object less dense than water**

Before beginning, draw a free-body diagram showing the forces on an object (less dense than water) partially submerged in water. Do the directions of the forces shown depend on the density of the object, or just their magnitudes?

Replace the aluminum cylinder with the wood cylinder, which attaches directly to the force sensor by a screw. **Do not remove the threaded screw in the top of the wood cylinder!** Its mass is negligible relative to the mass of the cylinder itself. **Do not screw the cylinder more than 5 mm**
(about 1/4 inch) into the force sensor. The force sensor can be damaged by screwing it in too far.

Again, measure the buoyant force as the submerged portion of the cylinder is increased in 1-cm increments. Do the buoyant force and the weight of the displaced water obey the same relation in this case? Discuss/explain.

**Relative density of aluminum and wood**

In your notebook, show that the density of any solid unknown material $\rho_{\text{Unknown}}$ obeys the following relationship:

$$\frac{\rho_{\text{Unknown}}}{\rho_w} = \frac{W_{\text{Unknown}}}{F_{\text{MaxBuoyant}}}$$

(10.4)

where $W_{\text{Unknown}}$ is the weight of the unknown object, $F_{\text{MaxBuoyant}}$ is the maximum buoyant force on the object (that is, the buoyant force when it is totally submerged in water), and $\rho_w$ is the density of water.

Use Equation (10.4) to calculate the density of the aluminum and the wood. Compare your calculated densities with accepted values from a textbook or handbook. A copy of the Handbook of Chemistry and Physics should be in your lab room. The density of natural wood can vary considerably, but the handbook should list some kinds of wood with densities that are consistent with your measurement. List some examples in your notebook. In contrast, the density of aluminum should not vary more than 0.05%. Does your measured density for aluminum agree with the handbook value within the limits of the expected error for this experiment? If your measurement and the handbook value disagree by more than three standard deviations, carefully examine your calculations and procedures for sources of error.

**Some questions for extra credit**

For extra credit, you may address the following questions in your notes:

1. How can an aircraft carrier (or a concrete canoe) float when the density of the material used to build it is greater than the density of water?

2. Does air create a buoyant force? If so, estimate the magnitudes of the buoyant forces due to the atmosphere on your wood and aluminum cylinders?

3. Is the direction of the buoyant force always opposite the direction of the gravitational force?

4. Does the buoyant force on a totally submerged object change as the object moves farther and farther below the surface of the fluid?
Before you leave the lab please:
- Quit Capstone.
- Replace the small hook in the force sensor.
- Straighten up your lab station.
- Report any problems or suggest improvements to your TA.