Lab 1: Buoyancy Calculation Example, Conceptual Questions, & Reference Material

This two-week lab consists of conceptual questions, calculations of the submerged volumes and stabilities of different orientations of the 3D shapes in your lab kits, and comparison of predictions and experimentally observed data. Submit your answers to conceptual questions, calculations, drawings, and the tables (one for each week) in one PDF document on GradeScope.

**Shapes: Dimensions, Masses and Select 3D Centroids**

Shape

Description automatically generated

**Helpful Formulae**

**Volumes**

Right Circular Cone

Equilateral Triangular Pyramid

Square Pyramid

Equilateral Triangular Prism

Ellipsoid

Spherical Cap (For sphere of diameter a, with submergence depth H)

**Centroids and Moments of Inertia for 2D Shapes**

**Diagram, engineering drawing

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Crowe and Elger, Fluid Mechanics; https://byjus.com/jee/moment-of-inertia-of-a-triangle/

**Instructions and Concept Questions**

**Week 1:**

**Table 1: Volume Calculations, Stability and Submerged Depth**

For each shape, first calculate the volume of the shape, and the density of the material using the table of provided masses. Then sketch out all possible orientations of each shape in a bath that are characterized by some degree of symmetry. Label sketches with variable names (a, b, h) so you can work symbolically. For the orientations in the [table](https://github.com/PrincetonUniversity/MAE224-Spring2021/blob/main/Lab1_Week1_ShapeTable.docx) (Week 1), calculate the submerged volume and the stability of the shape when placed in that orientation. You will turn in your calculations with your completed table. One shape has been done for you.

**Concept Questions**

1. “For a fluid with constant density, the buoyant force is independent of the distance of the body from the free surface. It is also independent of the density of the solid body” (Cengel, Fluid Mechanics). Imagine a foam ball and a wood ball of the same volume are released from the bottom of a swimming pool at the same time. Which will reach the surface first? Why?
2. Read the [article](https://github.com/PrincetonUniversity/MAE224-Spring2021/blob/main/Tip_of_the_iceberg_edited.pdf) “Tip of the iceberg” by Henry Pollack from Physics Today (2019). (A link to the article can also be found on the GitHub page for this lab.)
   1. What is wrong with Figure 1 of the paper? How would you correct the image? (Hint: Your answer should include a drawling.)
   2. What are the domains (I-IV) found in Figure 2? What are their characteristics?
   3. Given the dimensions and mass, where would the cylinder blocks in the lab kits fall on Figure 2?
   4. For each of the domains (I-IV), describe a cylinder (values of a, b, and ) that is stable there.
   5. What are some of the reasons ice density can vary?

**Week 2:**

**Table 2: Experimental Observations and Comparison with Predictions**

For each shape in the [table](https://github.com/PrincetonUniversity/MAE224-Spring2021/blob/main/Lab1_Week2_ShapeTable.docx) (Week 2), measure the submerged volume and sketch the stable orientations. Compare these observations with predictions from last week. Finally, find dimensions that would make the orientation shown stable. Submit any extra calculations along with the completed table and your answer to the concept question below.

**Concept Question**

1. Why don’t we subtract buoyant forces when weighing ourselves in air? (Hint: Compare the weight and buoyant force of a 58 kg woman in air. Assume her density is similar to that of water.)

Diagram

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**Example Calculation with Square Prism**

**Determine the submergence depths for the orientations shown at left, where the surrounding fluid is water** ().

The volume of the block is . Therefore, the density of the block is . Starting with first principles (), we establish a coordinate system and sum the forces on the block.

The displaced volume divided by the cross-sectional area is the submergence depth.

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|  |  |

**Are the orientations stable? What direction will the blocks rotate if unstable?**

If the metacentric height () is negative, the orientation is unstable.

|  |  |
| --- | --- |
| Center of Gravity: (vertical block)  Center of Buoyancy: (vertical block)  This orientation is unstable and liable to rotate about both axes.  Shape, engineering drawing, rectangle  Description automatically generated | Center of Gravity: (horizontal block)  Center of Buoyancy: (horizontal block)  The moments of inertia are different about the two axes: or .  The unstable direction is marked below.  Engineering drawing, line chart  Description automatically generated |

What might a stable orientation look like?