Lab 12: External Flow

SAFETY SECTION: We will be dropping different sized spheres through different fluids that are in a 6.5 foot long clear 1.5 inch diameter PVC pipe. The different fluids are isobutanol, water, and glycerin. Please review the safety data sheets for isobutanol and glycerin here (https://github.com/clint-bg/tools). Glycerin is used in many products including food products. Isobutanol is an alcohol and will dry out your skin. Please wear gloves when working with the isobutanol. Please clean up any drips of any of the fluid with the provided rag. Please also be careful not to lean on or tip the entire setup over. Long pants, closed toed shoes and safety glasses must be worn.

Begin your lab by holding a team planning session (3 minutes):

1. Review the safety information above.
2. One person should serve as leader/coordinator. All team members should strive to make the team function better through various roles: observer, fisherman, timer, recorder, devil's advocate, etc. Ask for each other's input and opinions, help each other, and try to come to consensus after an appropriate amount of brainstorming and analysis.
3. Make a plan for how you will complete the lab activities. Each person should fill out their own lab report as activities are completed. At the end of the hour, after cleaning up, get the TA to initial the end of your report.

Background: External flow refers to fluid moving around the outside of an object. This flow can lead to a drag force (force in opposition to the movement) or a lift force (orthogonal to the movement). In this lab you will investigate drag (C_D), terminal velocity, and viscosity.

Project: To investigate drag, terminal velocity, and viscosity, you will drop spheres down through a column of fluid and determine the drag coefficient and or the viscosity.

You may use markings on the PVC clear pipes as a measure of distance, stopwatch (or phone) for time, calipers for measuring the sphere diameter, and a balance to weigh those spheres. In addition, making a video of a falling object, and counting video frames with an appropriate frame-by-frame or slow-motion viewing app, can also give more accurate time vs. position measurements (most videos are 30 frames/sec).

1. **Pre-Lab Preparation:** Answer the following questions to prepare for the data collection and analysis. The internet is your friend.
    a. What is meant by "terminal velocity" of a falling object?

    b. What is the formula for gravitational force on an object?

c. What is the formula for drag force on an object, in terms of fluid velocity (relative to the object), C_D, area, density? Describe what area is intended in the formula.

d. What is the formula for buoyancy force on an object, in terms of fluid density and volume? Describe what volume is intended in the formula.

e. What is the formula for force on the sphere (including gravity, buoyancy, and drag) when falling through the fluid?

f. What is the density of water, glycerin, isobutanol, and air at 20 ^{o}C in kg/m^3?

g. What is the viscosity of water, glycerin, isobutanol, and air at 20 ^{o}C in Pa-s?

h. Please use the calculation sheet here (https://github.com/clint-bg/tools/blob/main/FallingSphereKinematics.ipynb, click the 'open in Colab' link) to estimate the distance a 6 mm diameter steel sphere needs to reach terminal velocity when falling through glycerin, water, isobutanol and air in inches.

Glycerin: Isobutanol:
Water: Air:

i. Given the assumptions in the calculation sheet (C_D, etc.) what is the terminal velocity for each of the conditions you calculated in the previous question?

Glycerin: Isobutanol:
Water: Air:

j. What is Stokes Law and when does it apply and how might you use it to estimate the viscosity of a fluid?

k. What is the expression for the terminal velocity assuming Stokes flow?

l. As part of this lab, you'll also be retrieving the dropped spheres with either a basket (for the plastic spheres) or a magnet. When dropping the plastic spheres, first drop the basket into the fluid column. Remember to use the fishing pole to retrieve the spheres when you're done. Please also wipe off the very viscous glycerin with a towel on the fishing line as the magnet is reeled in.

2. Terminal velocity data collection and analysis
    a. Drop a 6 mm steel sphere through the column of glycerin, water, and isobutanol and measure the terminal velocity.

       Gylcerin: Isobutanol:
       Water:

    b. Compare your terminal velocity measurements with your predictions above. Comment on differences or agreement.

    c. Drop the largest steel sphere through the glycerin and measure the terminal velocity. How does it compare with the smaller sphere? Why?

3. Drag coefficient estimation:
    a. Measure the diameter and density of the red plastic sphere (with calipers and the scale):

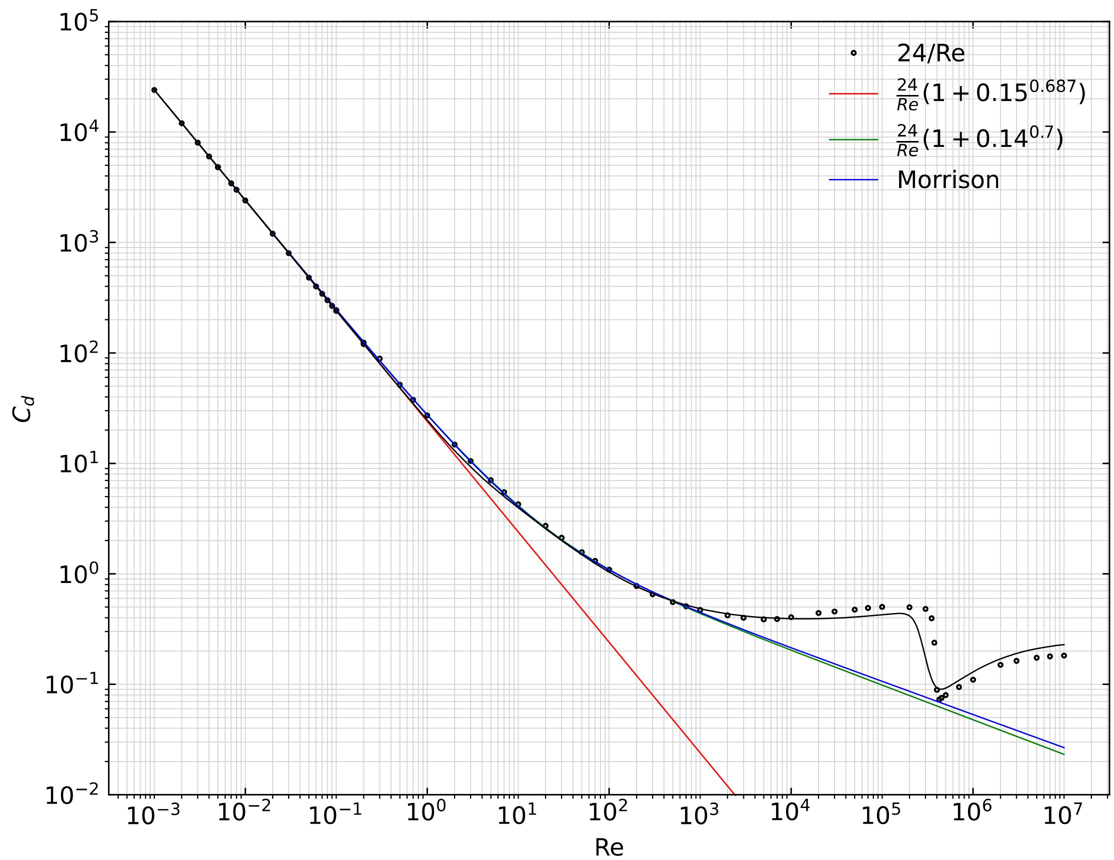
       Diameter: Density:

    b. Drop the red plastic sphere through the column of water and measure the terminal velocity (remember to drop the retrieval basket first).

c. Modify the code in the calculation sheet (simply change the Cd function to report a single value that you can change manually to give the same terminal velocity you measured) to estimate the drag coefficient for the plastic sphere in water.

d. Calculate the Reynolds number for that terminal velocity in water with the red sphere.

The drag coefficient for spheres is a function of Reynolds number that has been correlated for many different Reynolds numbers. Add a point (manually) to the following figure for your drag coefficient estimate at the given Reynolds number.



a. Why might you not expect the plastic sphere to fall through the glycerin?

4. Viscosity estimation:

One way to measure the viscosity of a fluid is to measure the drag force on a sphere with low fluid velocities (low Reynolds numbers). Under such conditions, the Stokes law may be applicable.

a. Drop the red plastic sphere through the column of isobutanol and find the terminal velocity and Reynolds number. Don't forget to drop the retrieval basket first.

b. Use your expression for the terminal velocity in the prelab assuming Stokes law to calculate the viscosity of the isobutanol from your velocity measurement.

   Isobutanol viscosity estimate:

c. Comment on why (or why not) your viscosity matches with the reported value of viscosity for isobutanol.

5. Terminal velocity estimation in a liquid-liquid phase:

   a. Drop the red plastic sphere through the isobutanol and water liquid-liquid system and measure the terminal velocity in both fluids. Don't forget to drop the retrieval basket first.

   b. Comment on any differences from the terminal velocity in the pure components versus the value you just measured.

   c. What are some things that happen when the sphere passes through the interface between the fluids?

Grading Rubric (to be completed by TAs)

	Points	Max
Completed Activities and write-up		7

Measurements and calculations accurate			7
Safety and cleanup; TA **initial:______**			1
	Total		15