HW 2: Making sense of experimental data and drag

I. READING AND LECTURES

To support this homework

- Re-read chapter 2 from the book.

II. COIN DROP EXPERIMENT

In the coin drop experiment we dropped several sets of disks into the pool and recorded some basic data. The data included the basic regime of behavior - steady, flutter, chaotic, or tumble. We also recorded the fall time, the probability of landing heads or tails, and the final distribution. All the data was accumulated by the different groups for you to analyze.

Your task is to try and make sense of all the experimental data from the class. Try to propose two dimensionless numbers that can describe the basic falling regime. Try to develop a phase diagram that plots the regime on a two-dimensional space of the dimensionless numbers. Look at the probabilities of what orientation the coin lands and the photos of the final distributions in light of your dimensionless numbers. Our data will be limited so there are likely multiple plausible answers at this point in time. Propose a next set of experiments that you would try to confirm or refute your hypothesis. If there are dimensionless numbers that you neglected as being unimportant, explain what you neglected and what experiment you could try to confirm or refute your assumption.

From the timing data, estimate the drag coefficients for the different falls. Look at the difference in drag coefficient (if any) based on the regime of falling.

Note that this is an experiment and the results may not be particularly clean. There is not necessarily a "right answer" I am looking for in this problem. I just want you to use dimensional analysis to try and make some sense of an experiment. Even though the concept of the experiment is simple, the results are quite complex.

III. DRAG ESTIMATES

Recall from Chapter 2, if the flow is dominated by viscosity that dimensional analysis gave a force on a sphere to have a form

$$F = C\mu U D,$$

and if the flow was dominated by inertia the force had a form

$$F = C\rho U^2 D^2.$$

In both cases, the constant C (or Drag Coefficient) is unknown until one conducts additional analysis (we don't know how to do this yet), numerical simulations (we don't know how to do this either), or experiments. Fortunately, for many common shapes drag coefficients have been measured and can be found in books or the internet. When using drag coefficient data you must take care in noting the form of the formula, and what area or length scale is used. Most drag formulas are written assuming inertia dominated flow and use a form

$$F = C_D \frac{1}{2}\rho U^2 A.$$

where A is often the area projected by the object to the flow. Again, the area used in the formula should be reported along with the drag coefficient (often it is not) to avoid any ambiguity.

The transition between the inertia dominated flows and viscosity dominated flows is given by the Reynolds number, defined as

$$\mathrm{Re} = \frac{\rho U D}{\mu}.$$

The Reynolds number is usually large for things that you interact with on a daily basis - a 1 mm object traveling at 1 mm/s in water will have a Reynolds number of 1. What counts as high or low Reynolds number depends on the situation, but usually greater than 1000 would be considered well in the high Reynolds number regime.

In all the problems of this section, state your assumptions. The following are estimates only - that is important to remember. For each estimate, you can use any resources you can find to get drag coefficients. For each problem, estimate the Reynolds number.

- It is often stated that baseball players can hit the ball further in Denver than at sea level due to the thinner air. Could this be true? How big of an effect (if any) is there?
- How much power is lost to drag on a typical car going 55 mph? 75 mph?
- During a category 1 hurricane, what is the force exerted on a stop sign?
- During a thunderstorm, hail is created when strong updrafts can keep large pieces of ice aloft. When the ice grows to a mass too great, the wind can't hold it up and the ice falls down as hail. How strong are the updrafts needed to create golf ball size hail?
- A dragster going 100 mph has a parachute with a cross sectional area of 4 m^2. What is the deceleration at the instant it is deployed (in g's)? How long will it take to come to rest?
- A sperm cell about 4 microns in diameter (assume a sphere) can propel itself at about 50 microns per second. What is the power density (power per unit volume) that this cell needs to maintain this motion? The cell can complete its trip in about 100 minutes - what is the energy density (compare to a battery)? To help with the drag calculation - Google "Stoke's law".
- Cut an index card into a few disks of different sizes. Try to get a thickness (tape a few pieces together if needed) so that the disk falls relatively straight; or at least not in the tumbling regime. Take a handful data points of terminal velocity (with a lab partner) and compute the drag coefficient for a disk. Compare the value you get to ones reported online. Check to see if you can note any Reynolds number dependence on the drag coefficient in your data. Try a quick check using a video from your phone camera to see that your disk is actually traveling at constant speed.
- Using dimensionless drag coefficients allows us to build and test models - the drag on different sized spheres is the same if the Reynolds number is the same. Assume you want to know the drag coefficient on a complex object like a car. You decide to build a smaller model and place that model in a wind tunnel. Assume different sized wind models and compute what flow speed you would need to get the same Reynolds number. Is there anything fundamentally different in a wind tunnel test than real life? Think about how you would practically do this experiment. Note, I am asking you actually think about this question and am not really looking for a particular answer.