

✓ Objects in flight

Run the Code Cell below to mount your Google drive.

```
1 #start up
2
3 from google.colab import drive
4 drive.mount('/content/drive')
```

Fill in the "... " in the code cell below with the directory information where your utilities file is located on your Drive. For example, if your file is in a folder called Colab Notebooks, you would change the code cell to be:

```
%run "/content/drive/My Drive/Colab Notebooks/utilities.ipynb"
```

Then run the code cell.

```
1 %run "/content/drive/My Drive/.../utilities.ipynb"
```

✓ Learning goals

By the end of this unit, you should be able to:

- Use physical models to make predictions and check whether results agree or disagree with predictions.
- Conduct follow-up experiments to explain why results disagree with predictions or to further probe a model when results agree with predictions.

Getting started

We're going to continue our model testing investigations, this time to examine the motion of objects in vertical flight (up and down). We'll start by testing two simplified models about the forces that act on the objects in vertical flight:

Model 1: The only force on the object is due to gravity.

Model 2: The only forces on the object are due to gravity and air drag.

Note: By averaging several sources, we estimate that $g_{Ithaca} = 9.80296 \pm 0.00011 \text{ m/s}^2$, although a change in altitude of 10 m may change the value by 0.00003 m/s^2 .

To design our experiment today, we're going to consider what evidence might help us distinguish whether one, the other, or neither of these two models are accurate representations of objects in vertical flight.

In a brief sentence, what basic physical properties characterize the air drag force?

[Your answer here]

Draw a free-body diagram for each of the models when the object is on the way up and on the way down (i.e. four free-body diagrams). Assume the drag force is smaller in magnitude than the weight of the object.

[Your FBDs here]

(upload an image from your computer using the "picture" icon above)

For each of the four free-body diagrams, predict how the object's acceleration should compare with the acceleration due to gravity alone (e.g., is the magnitude equal to/less than/greater than and in the same/opposite direction?). You should have four predictions: one for each model on the way up and one for each model on the way down.

[Your FOUR predictions here]

Ideally 15-20 minutes to get the predictions done. It IS ok to have a whole class discussion to make sure everyone's on the same page.

✓ Designing an experimental plan

Next, we'll design an experiment to test which model better describes your data.

To collect data, you can use the sonic rangers connected to the lab computers to monitor and graph positions and velocities as functions of time. First, try out the apparatus to see what it can do and how the software works. After playing around, talking to other groups, and (if others don't have answers for you) talking to the TA, start your experimental design by answering the following questions.

In one or two sentences, what does the sonic ranger do and how can you use it to measure acceleration of an object in vertical flight?

[Your answer here]

There are multiple ways to measure acceleration from the sonic ranger data. One way is to ask LoggerPro to plot the acceleration as a function of time. Another way is to ask it to plot the velocity as a function of time and then find the slope of your region of interest.

Why might it be better to estimate the acceleration from measures of velocity rather than from the software's estimate of the acceleration?

[Your answer here] Likely their questions will warrant going into the physics of the device - go there with them!
Of particular concern: We don't want them using LoggerPro's acceleration data because of the interpolations.

Note: To get the acceleration from the velocity data, select your region of interest (**what is the region of interest???**) -> click on Curve Fit -> choose Linear Fit -> then click Try Fit. A box should pop up over your selected region that gives you the slope with an estimated uncertainty value.

What are your main sources of uncertainty in estimating the acceleration and how will you quantify them? Justify your decision considering, for example, whether you necessarily need to conduct repeated trials for each object, if the uncertainty measure from Logger Pro sufficiently capture your sources of uncertainty, or if there are more systematic (rather than random) differences between trials.

[Your answer here] It may not be appropriate to combine repeated trials due to potential systematics between the trials (e.g., are they moving through the same height). They may also just not need them - a longer path (i.e., more data) for a single trial may be more effective and efficient. They can decide though and provide a justification.

Where along the object's path will you measure acceleration and at how many positions along the trajectory? Consider, for example, the benefits and drawbacks of averaging measurements across a range of the object's trajectory. Justify your decision, referring also to your free-body diagrams and their predictions.

[Your answer here]

✓ Data and analysis

Use the code cells below to record and analyze your data. Some code that may be of use to you is given below and you are welcome to copy over code from last week, write your own, etc. Be sure to comment your code so it's clear what data the analyses and outputs correspond to. You can also create separate code cells to run different analyses separately.

[State what your object is here]

```
1 # Object 1 data
2 ## Measurements of acceleration on the way up and down (# of Trials = ... , Other details = ...)
3 O1_acc_up_data = np.array([...])
4 O1_acc_down_data = np.array([...])
5
6 ## Estimate of the acceleration on the way up and down (e.g., mean if # Trials > 1)
7 O1_acc_up_est = ...
8 O1_acc_down_est = ...
9
10 ## Uncertainty in the estimate of acceleration on the way up and down (e.g., SU if # Trials > 1)
11 O1_acc_up_unc = ...
12 O1_acc_down_unc = ...
```

```
1 # Comparing measurements to predictions from Model 1
2
3 ## Predictions
```

```

4 M1_acc_up_pred = ...
5 M1_acc_up_unc =
6
7 M1_acc_down_pred = ...
8 M1_acc_down_unc =
9
10
11 ## Compare data to Model 1
12 t_M1_O1_up = t_prime(M1_acc_up_pred, M1_acc_up_unc, O1_acc_up_est, O1_acc_up_unc)
13
14 t_M1_O1_down = ...
15
16 print("Way up: Acceleration = " + str("%.2f" % O1_acc_up_est) + " m/s^2 +/- " + str("%.2f" % O1_acc_up_unc) + " m/s^2")
17
18 print("t-prime (compared to Model 1 prediction) = " + str("%.2f" % t_M1_O1_up))
19
20 print("Way down: Acceleration = " + str("%.2f" % O1_acc_down_est) + " m/s^2 +/- " + str("%.2f" % O1_acc_down_unc) + " m/s^2")
21
22 print("t-prime (compared to Model 1 prediction) = " + str("%.2f" % ...))
23

1 # Comparing measurements to predictions from Model 2
2
3 ...

```

Time stamp:
Students should have One object + one comparison
by an hour in

Briefly summarize your results above and comment on whether your results indicate which, if any, of the models describe your data.

[Your answer here]

Based on your results, design and conduct a follow up investigation, such as:

- If your data are described by BOTH models, work with your group to design an improved procedure to better distinguish them.
- If your data reject one of the models, repeat your procedure with another object and/or design a new experiment to further test the remaining model.
- If your data are not described by EITHER model, check your predictions, repeat your procedure with another object and/or construct a new model that is consistent with your data and design a new experiment to test the new model.

Notes about philosophy of science: A Popperian "falsification" view of science is one where models can only be proven to be false – they cannot be proven true. Thus, evidence in support of a model does not prove the model is true – it only adds weight to the evidence in favor of the model. Evidence that refutes a model, however, does mean the model is false (or limited). Further, evidence that rejects one model does not necessarily mean that the other model is correct.

[Your follow-up design here, including justification that draws on the items above]

```
1 ## Your follow-up data and analysis here, copying code starters from above
```

[Your summary and interpretation here]

Note: You should not remove anything above to replace it with "good" experiments or data. There is no single correct experiment here and each experiment should necessarily inform the next. Showing your evolving process will be graded more highly than just documenting a single "good" experiment.

Continue exploring your objects in flight, iteratively proposing modified methods and models to explain your results. Continue to document your methods, results, and interpretations by adding Text and Code cells below.

By the end of the lab, you should have tested several models and several objects and generated new questions or avenues for investigation about objects in flight.

Students should have time to test multiple objects and/or seek lower precision. Yes And...

Common questions:

* Should I measure a vs t , v vs t , or d vs t to get the acceleration?

Use Socratic Questioning to get students to realize that using v vs t and calculating the slope is the best option. Ask them how the sensor works (and help them figure it out), then ask them how it gets velocity and acceleration, and then fill in the blanks about why the a vs t graph may be complicated (e.g., noisy, over/under smoothing, including data points you don't want it to include, etc.).

* How do I measure uncertainty and do I need repeated trials?

Use Socratic Questioning to get students thinking about the sources of uncertainty and variability in these experiments and how systematics play in. More data is always better, but combining measurements from different trials may have systematic differences. e.g., If drag matters, the drag force will depend on the speed, which is likely not going to be consistent between trials, so combining them doesn't make sense. They can test if values are distinguishable between trials if they want to or dropping the objects should be consistent. Ultimately, they can get the uncertainty from estimating the slope across a *purposely selected* range of data points.

* What data can we throw out?

This lab is a great exercise in the ethics of data selection. Let them figure it out, but make sure they are always justifying what data to keep or not. Key question: is the data measuring the same phenomenon?

• Should we drop, throw, or bounce? Up to them! Get them to justify their decision

Key here is to keep them exploring. When in doubt, have them test other objects to see if their results hold and make sure they've tested all three positions/types of motion (moving upwards, moving downwards, when stationary at the top). Between these, they should obtain a contradiction somewhere, leading them to do some fun exploring and "problematizing."