I. Before you come to lab

- Read through this handout in its entirety.

II. Learning objectives

1. Learn what center of mass means and how to locate it
2. Learn how to apply Newton's 2nd Law to a complicated system (*e.g.*, a jumping person)

III. Materials

<u>Force plate</u>

The force plate is simply a flat plate that can measure the normal force exerted by it.

By itself, the force plate is basically just a bathroom scale. But when you use it to do data collection with Logger Pro, it can show you the normal force as a function of time, which is quite powerful.

The reading given by the force plate is the *y*-component (upward component) of the *normal force that the plate exerts on you* while you are standing on it. So this reading is positive if the force plate is pushing up on you, but negative if the plate is pulling down on you. (The latter would be quite rare—unless you are wearing sticky shoes, the reading would just go to zero when your feet are no longer in contact with the force plate.)

There is a switch on the force plate that toggles between the two ranges: between -200 N and +800 N, or between -800 N and +3500 N. We'll use the latter setting; with this range, the force plate reading has an uncertainty of 1 N.

The force plate is pretty sturdy, but it can be permanently damaged if you apply very large forces to it (greater than 5000 N). So you should feel free to stand or jump on it, but don't actively attempt to destroy it, because you might succeed.

<u>Digital video camera</u>

You've seen this before, in Lab 2.

<u>Stickers</u>

<u>Meter stick</u>

IV. Warm up

Suppose you are lying horizontally with your arms at your sides. You then raise your arms so that they are pointing straight over your head. Your center of mass in this position is located a distance Δx from the location of your center of mass when you have your arms to your side.

Determine an algebraic expression for the total mass of both of your arms, in terms of your total mass *M*, the horizontal distance Δx, and any lengths that you would need to measure on your own body (define these clearly in your answer).

Assume that the center of mass of each arm is located at the elbow. Make sure you include your work here, and show your result to your TF before moving on.

When you raise your arms, does your center of mass move towards your head or your feet? Explain.

V. Procedure

Tell us who you are (picture, names, and emails please)

A:

Part 1: Locate your center of mass

For this part, you'll have to work together with your neighboring lab group. Each group has a long board, a force plate, some tape/stickers, and a meter stick. You will need to devise a procedure for finding the center of mass for at least one of your group members. (*Hint*: start by putting the board across the two force plates and zeroing both of them.)

Write your explicit procedure for locating your center of mass here:

A:

Everybody is encouraged to locate his or her CM and mark it with a bright sticker; however, *at least* one person from each group of 3 must do it. **Where is your center of mass located?**

A:

Part 2: Move your arms

Still working with your neighboring group, devise a procedure to answer the following question:

Suppose you are lying horizontally on the board with your arms at your sides. If you then raise your arms so that they are pointing straight over your head, what distance Δx (in cm) does your center of mass move in the horizontal direction?

Write your explicit procedure to measure Δx:

A:

Now perform this procedure for at least one member of each 3-person lab group (it should be somebody whose CM you located in the previous part). Record any measurements you made, with uncertainties, here:

Δx:

Uncertainty in Δx:

Now let's plug in some numbers. The assumption that your arm's CM is at the elbow has an uncertainty of about 2 cm. Using the algebraic expression you found in the warm up, **what is the total mass of both of your arms, with uncertainty? Make sure to include all your work, and any extra measurements you made.**

Mass of arms:

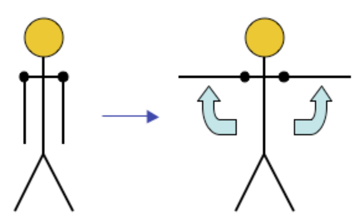
Uncertainty in mass of arms:

Part 3: Move your arms again

This section of the lab involves working with your original group of 2-3 people, so you can split back up into your regular groups at this point. Also you can remove the long board from both force plates and place it against the wall. You won't need it again.

(Click the Collect button in Logger Pro and see what happens. The force plate will then collect data for 10 seconds; you'll see the trace appear on the graph. If you ever need a do-over, just click on the Collect button again and take another 10 seconds of data.)

Have one member of your group stand on the force plate with arms down at his or her sides. (*Hint:* make sure you zero the force plate first!) While collecting data, have the person who is standing on the force plate quickly raise their arms so that they are pointing outwards, and then keep them there for the rest of the 10 seconds, as shown at right.



Qualitatively, what features do you observe in the graph?
A:

Paste the graph of the normal force vs time here:
Graph:

Is the reading on the force plate the same at the end as at the beginning? Why or why not?
A:

Why does the normal force change as you move your arms up? Explain your observations in terms of what you know about Newton's Laws.
A:

Make a qualitative sketch of the height of the person's center of mass as a function of time during the 10 seconds. Take a picture of it and include it here.
Sketch:

Part 4: Jump!
In this part, you will have the opportunity to explore the physics of a standing jump. We encourage everybody to take a turn jumping on the force plate (you may opt out if you wish), though the full analysis should only be done for *one jumper per group*. You will record a standing vertical jump, using both the force plate and the video camera.

Refer to the supplemental materials for this lab and **check that everything is ready to collect the jumping data**. When you are ready to start filming, click Start Capture. Both the camera and the force plate will begin collecting and recording. (If this doesn't happen, go back to the supplemental material and make sure the Video Capture settings are correct.) The capture should run automatically for 10 seconds and then stop.

During the 10 seconds, **jump up as high as you can and land back on the force plate**. Repeat as necessary, until you get a clean data run (person jumped straight up/down, did not bump into things, did not fall off the force place, etc.)

To continue analyzing your data, you will need to **synchronize the movie to the force plate data**. Although both are collected at the same time, they are on slightly different clocks, so they are not really synchronized to begin with. Instructions on how to do this can be found in the supplemental material.

On the force versus time graph, determine the time at which each of the following events occurs. Mark the location on the graph with a Text Annotation. (Careful! some of these are trickier than they look)
1: The start of the crouch preceding the jump
2: The highest point of the jump
3: The jumper's center of mass reaches its maximum downward velocity during the crouch
4: The jumper's center of mass reaches its maximum upward velocity
5: The lowest point of the crouch
6: The jumper's feet touch the ground at the end of his jump

Paste a copy of the **force versus time (with annotations)** graph here
Graph:

How long were you in the air? Determine this from the force graph. You will need to zoom in on the graph to measure it accurately.
Flight time t_f =

If we assume that the takeoff and landing occur at the same *y*-position, we can actually calculate the maximum height reached during the jump from the t_f alone (and g). **Find an algebraic expression for the height of the jump in terms of t_f and g.** Make sure you show your work, and check your answer with a TF before moving on.
Expression:

From the flight time, **calculate the height of your jump**.
Jump height (from flight time) =

Use Video Analysis to **track the motion of your center of mass** (conveniently marked with a label in the movie). Use the meter stick to set the scale. You don't have to mark every frame in the video; begin just before you start to go down into your crouch and stop when you touch down at the end of the jump.

Display on your graph both the force and the CM position simultaneously. Paste a copy of your graph (showing both Force and Y vs Time) here:
Graph:

From the video analysis, **how much did you raise your center of mass from its initial position (when you were just standing there) to the top of your jump?**
Jump height (from video) =

Compare the results of the two methods of measuring the jump height. If they are way off, see if you can figure out why. (*Hint*: do the two methods measure the same thing?)
A:

The video analysis gives a simpler, more direct, and more reliable measurement. **How can you correct the time-of-flight measurement to make it comparable to the video measurement?**
A:

Can you use your formula above to get the jump height using this corrected time-of-flight? Why or why not?
A:

In the "Latest" data set, create a new calculated column called "Net Force" which gives the *y*-component of the *net* force on you. Remember, the force plate only reads the normal force.

In the "Video Analysis" data set, create a new calculated column called "ma" which contains your mass times the *y*-acceleration of your center of mass. (You'll have to take the second derivative of Y.)

Create a new graph that has both "Net Force" and "ma" on the y-axis, and Time on the x-axis. Zoom in on the region where both Net Force and ma are visible and paste a copy of it here:
Graph:

What do you observe about the plots? What can you conclude?
A:

What else would you need to know to determine if Newton's 2nd Law applied to the jump?
A:

VI. Conclusion

What is the most important thing you learned in lab today?
A: