

Lab 3: Forces

Learning Goals

After you finish this lab, you will be able to:

1. Use Logger Pro to analyze video and calculate position, velocity, and acceleration.
2. Measure the normal force exerted on an object (you) using a force plate.
3. Use your video measurements of position (y) to find the y -component of your acceleration, a_y .
4. Compare the net force with ma to see how Newton's Second Law holds for a complicated object (you) in a complicated motion (jumping).

The particle model for a complex object: use the center of mass!

In this lab, you'll explore Newtonian mechanics of an extended, non-rigid object: your own body. Whenever your center of mass accelerates, it must be due to a net *external* force; conversely, any time there is a net external force on your body, it will result in motion of your center of mass. This motion can be extremely non-obvious, because your center of mass can move as a result of a shift in body position rather than an overall movement of your entire body.

Recall Newton's 2nd Law for a particle or simple object: the sum of the forces on the object is equal to its mass multiplied by its acceleration. At this point in the course, you've used this fact many times to solve physics problems. Typically, we proceed by drawing the free-body diagram of an object and adding up all the forces on it and then using Newton's 2nd Law to equate the total force to the object's mass times its acceleration.

But what about an extended object or system, which can have many moving parts? For an extended object the net force is given by the the sum of the *external* forces on the system. But which acceleration are we talking about? Remember how we defined the concept of *center of mass*. Our definition of center of mass ensures that Newton's Second Law will hold if we treat a complex object with a total mass M_{total} as a particle of mass M_{total} **located at the center of mass**. That is:

The sum of all external forces on a system is equal to the total mass of the system multiplied by the acceleration of the system's center of mass:

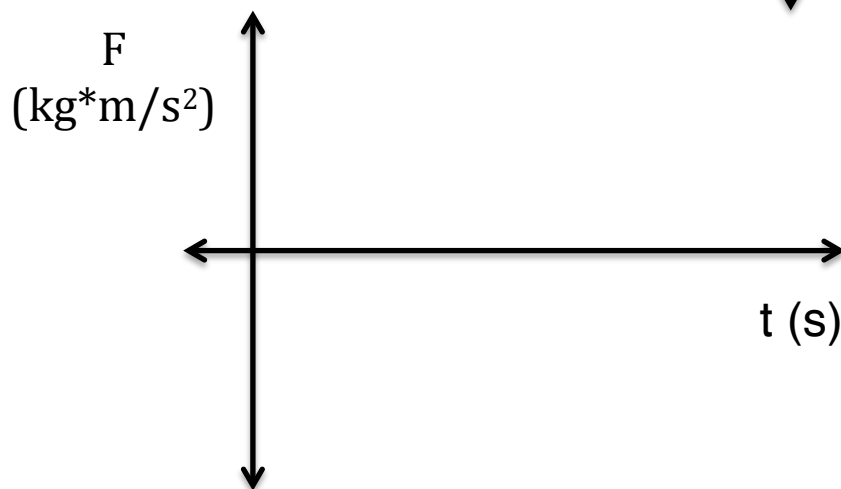
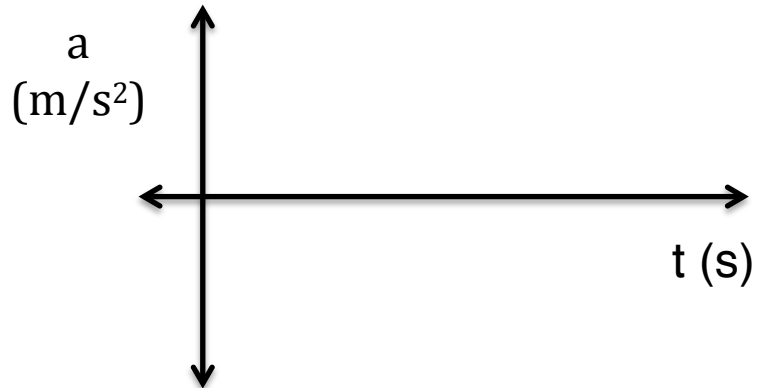
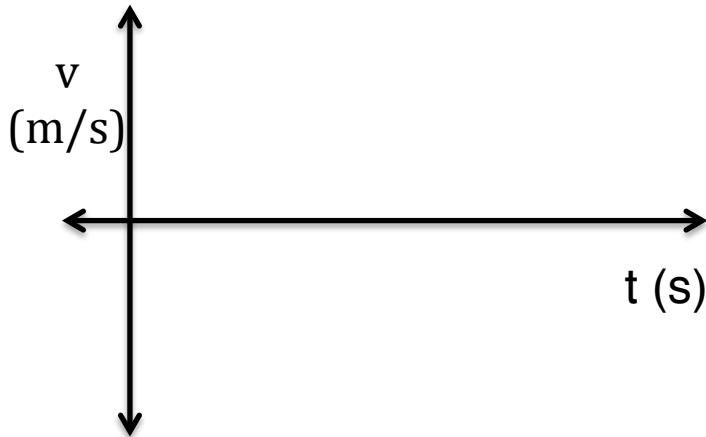
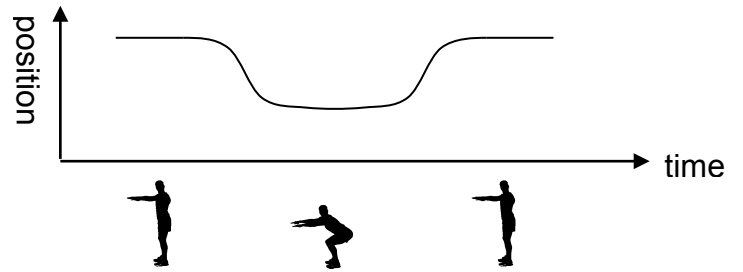
$$\sum \vec{F}_{\text{external}} = M_{\text{total}} \vec{a}_{\text{CM}}$$

This "particle model" represents an extraordinary simplification: we can model a complicated object like the human body as a simple point particle! But first we'll need to think about where the center of mass of a person is.

Warm Up: Deep Knee Bends

Imagine you stand on a scale, lower your body by bending your knees, and go up again. In the graph shown, the body position x (height) is plotted versus the time t . Sketch the graph you expect for the velocity $v=dx/dt$, and the acceleration $a=dv/dt$ of your body. Sketch a graph for the force that the scale would measure vs. time.

Sketch those here:



Part I: Collecting Force Data

Have a member of your group stand still on the plate. Have another member of your group click the Collect button in Logger Pro. The force plate will then collect data for 10 seconds; you'll see the trace appear on the graph. Then do a quick deep knee bend. **Separate the up and the down with a long pause.**



Q1. Using the trace on the graph, what is the mass of the person?

Mass = _____ kg

Use Logger pro and calculated columns and the calculus feature to create Fnet, acceleration, velocity, and displacement graphs. Hint: You will need to create a parameter for $g = 9.8\text{m/s}^2$ and for the mass of the person who jumped.

Q2. On a separate sheet of paper make a quick sketch of your calculated graphs. Include titles and axis labels. Attach graphs to the end of the lab report.

Q3. Explain the features of the graph and how they relate to the motion and position of the person at certain points:

- a. When the force is equal to zero, max, min, and the axis crossing

- b. Where is the person's velocity greatest in magnitude during the crouch? How do you know?

- c. Why does the trace of the force graph give both positive and negative readings for just the crouch down? Is the reading at the end the same as at the beginning? Should it be?

Part II: The Jump

Whether you are standing or jumping, the only external forces acting on your body are the normal force from the ground and gravity. How can you jump? Raising your center of mass into the air seems like it would require gravity to diminish or the normal force to grow. Why would either of these happen?

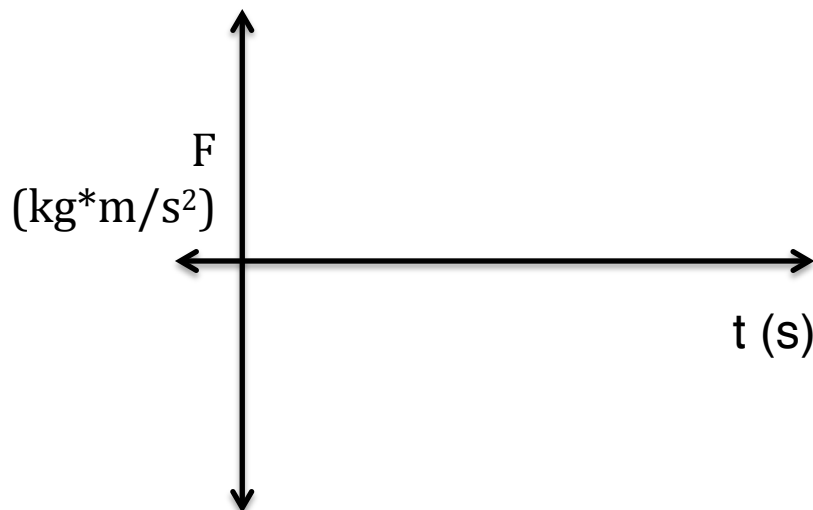
The one thing we know for sure is that gravity isn't changing. Therefore, it must be that the normal force from the ground increases as you jump, propelling you into the air. Because you push off harder on the ground with your legs, by Newton's 3rd Law, the ground must also be pressing harder on you.

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 computer web cam.

- **Open Photo Booth to video tape and simultaneously record force plate data in Logger Pro for someone doing a standing jump.**
- **Make sure the jumper is holding a meter stick.**
- **Also make sure to mark the person's center of mass with a bright piece of tape or sticker.**
- **Also make sure to have the jumper bounce their foot quickly off the plate in order to synchronize the video and force plate data.**

Create a Net Force vs Time graph of a standing jump using the force plate data. Create mass and g parameters as before.

Q4.) Draw a rough sketch of your net force jump graph here.



Q5.) On the above graph, determine the time at which each of the following events occur. Mark each point on the graph.

- 1: The start of the crouch preceding the jump
- 2: The jumper's center of mass reaches its maximum downward velocity during the crouch
- 3: The lowest point of the crouch
- 4: The jumper's center of mass reaches its maximum upward velocity
- 5: The moment of takeoff
- 6: The highest point of the jump
- 7: The jumper's feet touch the ground at the end of the jump

Q6.) How high did you jump?

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_{flight} =

From the flight time, calculate the height of your jump. Show Work

Calculate the maximum height reached during the jump from t_{flight} alone (and g).

Track Your Motion: Now use Video Analysis to track the motion of your center of mass.

- Export the video from Photo Booth and save to Desktop.
- In Logger Pro, Insert > Movie > the movie you saved.
- In the movie window in Logger Pro, click the tracking button in the bottom right to open the tracking menu. Click the tracker button (+) in the top right corner and then repeatedly click on the tape marker in the video to track the jumper's center of mass. You don't have to mark the entire duration of the video; start marking each frame just before you start to go down into your crouch and stop a little bit after you touch down at the end of the jump.
- In the movie window, click the "set scale" button and set the scale using the meter stick in the movie.
- In the movie window, click the "Sync movie to graph" button on the bottom right and set the movie on the frame where your group member bounced their foot before the jump and click on the corresponding spike in the Force Plate graph. (Make sure you sync to "Data Set: Latest")

From the video analysis, **how far did your center of mass move from the moment of takeoff to the top of your jump?**

Q7.) Start with the video analysis y-position data. Create velocity, acceleration, and Net Force graphs from the displacement vs. time graphs of the video analysis. Use Calculated Columns to perform the necessary operations. The destination of these columns should be "Data Set: Video Analysis"

At the end overlap the Net Force graph from the video analysis and the Net Force graph from the force plate data. Use separate axis for each graph (graph option – axis options- right y-axis)

Call over the TF to show and discuss your results.

TF Initials: _____

Conclusions:

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

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

What aspect of the lab was the most confusing to you today?