Lab 4: The Force Plate and Vertical Jump

I. Before you come to lab...

II. Background

III. Introduction

A. 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 next 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.

B. Objectives for this lab:

1. Observe Newton's second law applied to your body
2. Locate your center of mass
3. See how much your center of mass moves when you change your body position
4. Measure how high you can jump!

IV. Materials

A. Force plate

1. The force plate is simply a flat plate that can measure the normal force exerted on it:

2. Like the force sensor last week, the force plate connects to a computer via the LabPro interface, and data from it can be collected and analyzed using Logger Pro. Unlike the force sensor, the force plate can measure large forces up to and beyond the weight of a person.
3. There is a switch on the force plate that toggles between the two ranges. One setting is for measuring forces between -200 N and +800 N. (Negative forces correspond to pulls; positive forces correspond to pushes.) The other setting is for larger forces, between -800 N and +3500 N. On this setting, the force plate can be used to study a person standing or jumping on it.
4. The force plates are pretty sturdy, but they can be permanently damage if you apply very large forces to them (greater than 5000 N). In ordinary standing or jumping, the forces involved are quite a bit less than this, but if you intentionally stomp as hard as you can on it, or jump and land with your knees locked, you can exceed 5000 N and break the force plate. (Landing with your knees locked, in particular, is a bad idea on so many levels. Just don't.)

B. Digital video camera

1. This is simply a video camera connected to the computer that can be used to capture video in Logger Pro.
2. You've used these before, in Lab 2.

V. Procedure

A. Before you begin:

1. Take a picture of yourselves using Photo Booth and drag it into the space below:

2. Tell us your names:

B. Locate your center of mass!

1. For this part, you'll have to work together with the other lab group on the same (long) side of the table as you. Each group has one force plate; set them on the floor about 3 feet (1 m) apart.
2. Open Lab4.cmbl in Logger Pro.

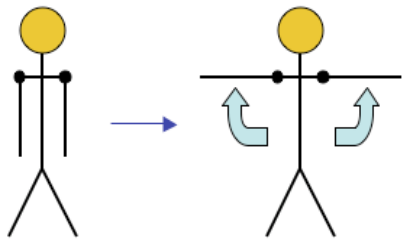
3. Place the long board so that it is resting on both force plates, with one support on each force plate:

4. On both computers, click the 

button to zero the force plate reading.
5. Place a 5-kg mass on the board, near the middle. Move it back and forth until both force plates give the same reading (to within 1 or 2 N).
6. Mark the position of the mass on the board with a piece of tape. This is the center of the board.
7. Remove the mass and zero both force plates again.
8. Take turns and lie down on the board with your arms straight by your sides, and do the same exercise you did for the 5-kg mass: slide towards one end of the board or the other until the force plates give the same reading (at least to within 5 N or so). Your lab partners will have to tell you which way to move.
9. Try to make sure the board does not slide relative to the force plates. If it does, you will have to redo steps 4-6 and re-mark the center of the board.
10. When the readings are equal, note the position on your body which is at the same location as the tape marking the center of the board. This is the location of your center of mass! Mark it with either a white label or a colored label (whichever one provides better contrast with the clothes you are wearing).
11. Repeat steps 7-10 for each member of both lab groups. When everybody has located their own center of mass, you can move on. The rest of the lab involves just working with your group of 2-3 people.

C. Move your arms!

1. Remove the long board from both force plates and place it on the table. You won't need it again.
2. Zero your force plate (with nothing on it).
3. Have one member of your group stand on the force plate with arms down at his/her sides.
4. Have another member of your group click the  Collect button in Logger Pro.
5. The force plate will then collect data for 10 seconds; you'll see the trace appear on the graph. During this time, have the person who is standing on the force plate should quickly raise their arms so that they are pointing outwards, and then keep them there for the rest of the 10 seconds:



If you need to do it over, just click on  Collect again and take another 10 seconds of data.

6. Paste the graph of the normal force vs time here:

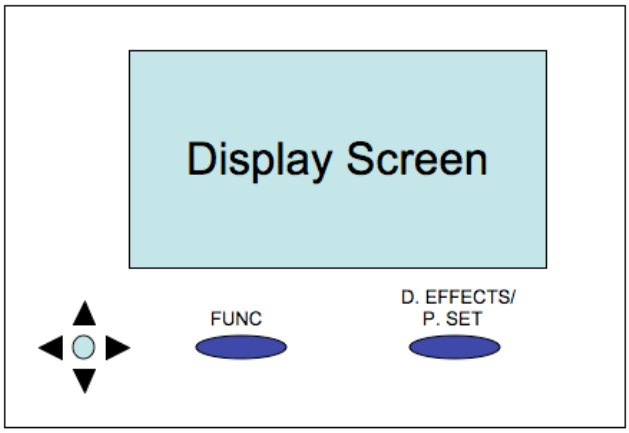
7. Explain the features of the graph. Why does it go both up and down? Is the reading at the end the same as at the beginning? Should it be?

8. 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:

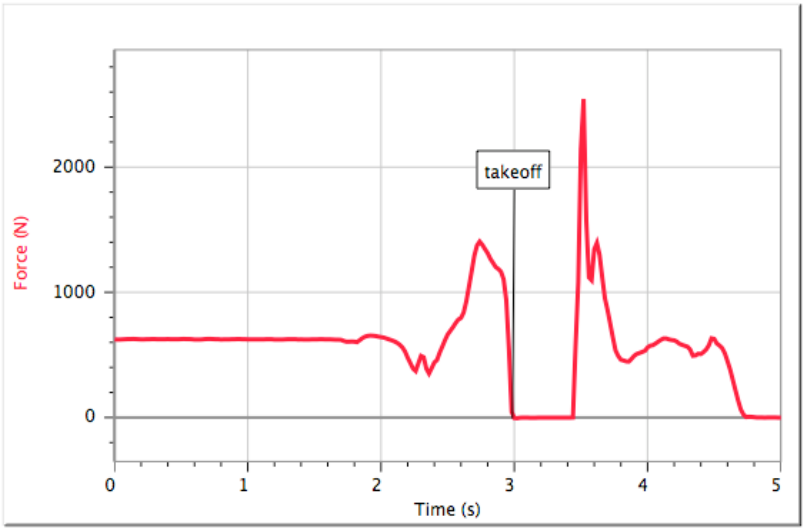
- **9.** Your arms have a mass of about 5 kg (each). Using this information, estimate about how much you moved your body's center of mass when you raised up your arms. (Hint: the CM of your arm is pretty close to your elbow.)

D. Jump!

- **1.** Change the DV camera shutter speed:
  - **a.** Look at the flip screen on your digital video camera. It looks something like this:



  - **b.** If your camera is in screen-saver mode, press the FUNC button to get it to stop. Press FUNC again to access the camera's settings.
  - **c.** The camera's menu will now appear on the display screen. To navigate the menu, use the little joystick. To select an entry, click the joystick (press into the middle instead of in one of the four cardinal directions). Start by clicking to get the menu.
  - **d.** Click again for CAMERA SETUP.
  - **e.** To change the shutter speed, press → and then click once. Press ↓ until the shutter speed is 1/500 of a second, and then click again.
  - **f.** To exit the camera setup menu, press FUNC again.
- **2.** Set up Logger Pro to take video captures:
  - **a.** In Logger Pro, go to the Insert menu and select Video Capture.
  - **b.** If it prompts you to select a camera, select DV Video.
  - **c.** If they ask for a resolution select 800x600 or 720x480.
  - **d.** If they ask for a sound source, it doesn't really matter; pick one.
  - **e.** The video capture window will open. On the right side of this window, click the Options... button.
    - **(1)** Video Capture Mode: Video Capture Synchronized with Data Collection
    - **(2)** Duration: 10 seconds
    - **(3)** Make sure "Time-Lapse Capture" is **not** checked.
    - **(4)** Capture File Name Starts With: MovieCapture
    - **(5)** Click on the Camera Settings button.
      - **(a)** In the Compression tab, under Motion, Frames per Second: 30
      - **(b)** Click OK. (Don't worry if it tells you that the compression mode is not the default.)
    - **(6)** Click OK.
- **3.** Zero the force plate.
- **4.** Have one of your group members stand on the force plate facing the camera. Make sure their CM label is clearly visible. Another group member should stand next to them holding a meter stick. You will record a standing vertical jump, using both the force plate and the video camera.
- **5.** When you are ready to start filming, click Start Capture. Both the camera and the force plate will begin collecting and recording. The capture runs automatically for 10 seconds and then stops.
- **6.** During the 10 seconds, jump up as high as you can, and land back on the force plate. You should see a force graph that looks something like this:



7. Synchronize the movie to the force data:

- **a.** The place where the reading on the force plate goes to zero is the moment of takeoff, i.e. when your feet lose contact with the force plate. You will use this moment to synchronize the video to the force data. (Although both are collected at the same time, they are on slightly different clocks so they are not really synchronized to begin with.) If you did the tutorial in the pre-lab, this will be a cinch.
- **b.**
  In the lower-right corner of the movie window, click the  button.
  - **(1)** A synchronization dialog box will open. First, click in the graph on the moment of takeoff. In the force graph above, this occurs at pretty much exactly t=3.0 seconds. You should see the time corresponding to your click appear in the dialog box. (You may need to click and drag the dialog box to somewhere where it won't cover up the graph you are looking at.)
  - **(2)** Next, play through the video frame by frame until you find the very first frame where your feet leave the force plate. The time corresponding to this frame will also appear in the synchronization dialog box.
  - **(3)** Now click OK in the dialog box to sync the movie
- **c.**
  Once the movie is synchronized with the force data, you can use the 

  button in the graph and the movie will automatically show the frame corresponding to the time you are examining. You can also set up a replay control (Analyze → Replay...) to watch the force plate trace and the movie at the same time, at whatever speed you like. It's pretty cool.

8. Analyzing your jump:

- **a.** Your name:
- **b.** Paste a copy of your force graph here:
- **c.** From the force graph, determine the time of flight, i.e. how long you were in the air. You will need to zoom in on the graph to measure it accurately.
  flight time =
- **d.** From the flight time, use kinematics to calculate the height of your jump:
  jump height (from flight time) =
- **e.** Now 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.
- **f.** After you have added the video analysis points, double-click on the force graph and go to the Axes Options tab. Check the box for Right Y-Axis and have it display the column "VideoAnalysisIY"; then click OK. Now your graph will display

both the force and the CM position simultaneously, and the 

feature will also show the corresponding frame in the movie.

- **g.** Paste a copy of your graph (showing both Force and Y vs Time) here:

- **h.** 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) =
- **i.** 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?)

- **j.** The video analysis gives a simpler, more direct, and more reliable measurement. Can you think of a method to correct the time-of-flight measurement to make it comparable to the video measurement? (Talk to your TF about this.)

  jump height (from time-of-flight, corrected) =
- **k.** When you have finished analyzing your jump, go to File → Save As... and name the file with your name, e.g. "Lab4-joon.cmbl". Put it in the Lab4 folder on the Desktop.
- **l.** Attach the Logger Pro file here (by dragging it from the Finder into the space below):

- **m.** Go to the blackboard and write your jump height there in centimeters. (Use the one from the movie.)

9. Now **open a fresh copy of Lab4.cmbl** and repeat the jump for another jumper, starting with step 2.

- **a.** Your name:
- **b.** Paste a copy of your force graph here:

- **c.** From the force graph, determine the time of flight:
  flight time =
- **d.** From the flight time, calculate the height of your jump
  jump height (from flight time) =
- **e.** You don't have to do the video analysis for every jumper; once is sufficient. However, recall that the time-of-flight measurement does not measure the jump height using the same definition of jump height. If you "correct" your time-of-flight measurement the same way you did with the first jump, what would the result be?
  jump height (from time-of-flight, corrected) =
- **f.** When you have finished analyzing your jump, go to File → Save As... and name the file with your name.
- **g.** Attach the Logger Pro file here (by dragging it from the Finder into the space below):

- **h.** Go to the blackboard and write your (corrected) jump height there in centimeters.

10. Now **open a fresh copy of Lab4.cmbl** and repeat the jump for the last jumper, starting with step 2.

- **a.** Your name:
- **b.** Paste a copy of your force graph here:

- **c.** From the force graph, determine the time of flight:
  flight time =
- **d.** From the flight time, calculate the height of your jump
  jump height (from flight time) =
- **e.** If you "correct" your time-of-flight measurement the same way you did with the first jump, what would the result be?
  jump height (from time-of-flight, corrected) =
- **f.** When you have finished analyzing your jump, go to File → Save As... and name the file with your name.
- **g.** Attach the Logger Pro file here (by dragging it from the Finder into the space below):

- **h.** Go to the blackboard and write your (corrected) jump height there in centimeters.

11. After everybody in the group has jumped, you can move on to the next part.

E. Is Newton's 2nd Law really true?

1. Open one of the files in which one of you saved your jump data. (You do not have to do this part for every member of the group.)
2. In the Latest data set, create a new calculated column called "Net Force" which contains the **net** force on you (in the y-direction). Remember, the force plate only reads the normal force.
3. In the Video Analysis data set, create a new calculated column called "ma" which contains your mass times the y-acceleration of your CM. (You'll have to take the second derivative of Y, or the first derivative of your y-velocity.)
4. Create a new graph which has both "Net Force" and "ma" on the y-axis, and Time on the x-axis. Paste a copy of it here:

5. Zoom in on the region where both Net Force and ma are visible. (It will only calculate ma for the times when you put a dot in the video analysis.) How well do the two curves track each other?

6. That's it for the lab this week. Hope you had fun!

VI. Conclusion

A. Submit your lab report online according to the instructions on the plastic sheet at your computer.

B. Super-duper important—don't even think about skipping this step! Before you leave the lab, every member of your lab group should open a browser and go to
http://physci.fas.harvard.edu/~yourFASusername
and make sure that your lab report is there under the link called "Lab 4." If not, then you haven't submitted it correctly; ask a TF for help. If your lab report isn't submitted, you won't get credit for doing the lab. Also, **make sure that if you scroll down in the lab report, your attached Logger Pro files are there**. You'll need those in order to complete your homework assignment this week.