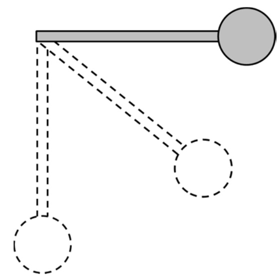
ES 204 Lab 2
Working Model Simulation of a Swinging Pendulum



The purpose of this lab is to use Working Model to simulate a pendulum and use the simulation to explore the behavior of the system. You will see that it is difficult to intuitively predict this behavior. By exploring the system in a simulation, you will begin to gain an understanding of the complexity of a rigid body in rotation.

In Lab 3, you will *experimentally* explore this same system. In a future homework assignment, you will predict the behavior of this system through *analytical* means using the material learned in class. If your simulation is well-built, the experiment is well-done, and the theoretical analysis is well-justified, all three methods will give similar results.

Build the Simulation

Be sure the units you are using are metric (SI) and radians (View/Numbers and Units). Set the mass units to grams and the distance units to centimeters (View/Numbers and Units/More Choices). It is often convenient to turn on a grid, rulers, and axes (View/Workspace).

Create the geometry

1. Set the view size window width to 230 cm (View/View Size).
2. Create a rectangle that is 43.2 cm long by 1.5 cm wide (height = 43.2 and width = 1.5 in the Geometry window) and has mass equal to 68.5 g to represent the pendulum bar.

Pin the pendulum to the background

3. Use a round pin joint (see the toolbar on the left side of the Working Model window) and pin the top middle of the bar to the background.
4. In the experiment you will conduct for Lab 3, the pendulum bar is actually pinned in a slightly different location due to the size of the rotational sensor. To reflect this, modify the second formula for the y-location of the pin to be

   Body[?].height/2.0-1.25

   where you need to replace ? with the bar's object number.

Create the adjustable weight

5. Create a circular object of radius 2.5 cm to act as an adjustable weight. Place a square point element in the center of the circle. Place another square point element in the middle of the bar and, while the square point element is highlighted, create a slider control to adjust the location of the circular weight along the pendulum bar (Define/New Control/Offset). Delete the x-offset control that appears. Double-click on the word "Y-offset" and set the minimum and maximum values to 0 and 40, respectively.
6. Select the square point element on the bar and change the y equation from "Input[?]" to

   43.2/2-1.25 – Input[?]

   When the offset is set to zero, the square point should be at the pin location of the bar.
7. Highlight the two square point elements (hold down the Shift key to select multiple objects) and then click on Join.
8. Create a control for the mass of the adjustable weight. Highlight the weight and choose Define/New Control/Mass. Double click on the word "Mass" and set the minimum mass to 1 g and the maximum mass to 1000 g.

Set the initial angle, and add graphs and meters

9. Set the initial angle of the bar to pi()/2 by double-clicking on the bar to bring up the Properties window and changing the angular position ϕ from 0 to pi()/2 rad.
10. Create a meter to measure the angular position and velocity of the bar. Highlight the bar and select Measure/Position/Rotation Graph. Click twice on the white arrow in the upper left of the meter and you will have a digital meter rather than a graph. Double-click on the graph to call up the Properties window and add a plot for the angular velocity of the bar. The equations for angular position and velocity should be something like Body[?].p.r and Body[?].v.r, respectively.
11. Create a meter to measure the time (Measure/Time).

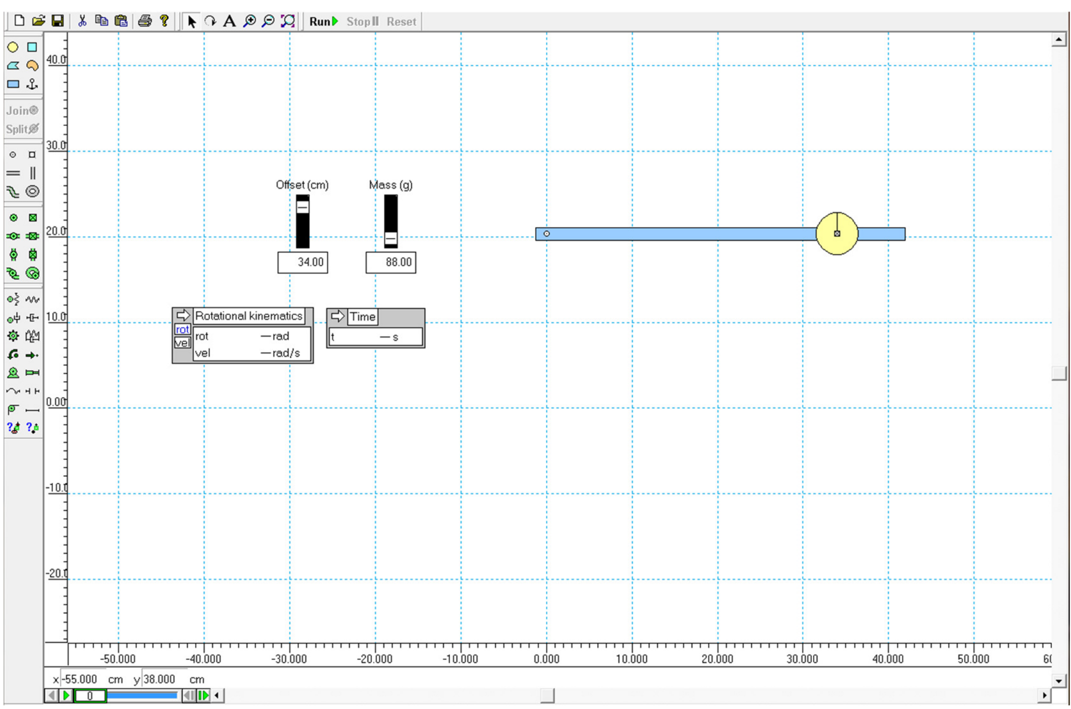
Add pause control and make final adjustments to the simulation

12. We want our simulation to stop when the bar crosses vertical, so let's add a pause control for the pendulum. Select World/Pause Control/New Condition and then type following condition:

    Body[?].p.r < 0

13. Eliminate all contact/collisions by selecting all the objects you have drawn and then going to Object/Do Not Collide.
14. Use an animation step of 0.001 and an integration error of 0.0001 (World/Accuracy).
15. Set the adjustable mass to 88g and place it at the end of the bar. When you run the model, the simulation should stop when the bar passes vertical.

A snapshot of what your model may look like is shown below.



Lab 2 Worksheet – Due with HW 5

Names ________________________ , ________________________ **CM** _____________

1. Set the adjustable mass to 88 g and adjust the position of the disk according to the table shown below. Run your simulation and record the time for the pendulum to reach the vertical position and the angular velocity at that instant.

Offset (cm)	Time (s)	Angular velocity magnitude (rad/s)
4		
9		
14		
19		
24		
29		
34		

   Using Excel, create a plot of time as a function of the offset and a plot of the angular velocity magnitude as a function of the offset. Print your plots on a single page and attach it to this worksheet.

2. Expand the table above using trial and error to determine the exact offset $L_{\text{max, WM}}$ (within 0.1 cm) for which the bar will have a maximum magnitude of angular velocity at the bottom of its swing. You must include a table of the points you used as part of your Excel printout.

   $L_{\text{max, WM}}$ = ____________________

   How does this compare to your solution to Problem 4.9 in HW 5? This question is to be answered after you complete Problem 4.9. **Attach a COPY of your solution to this worksheet**. Since you are working in teams of two, you only need to attach one solution.

   $L_{\text{max, HW}}$ = ____________________

3. Explore this problem using your simulation. For example:

   a. What happens to the offset for maximum angular velocity if you change the mass of the disk?

   b. At what disk offset from the pivot is the angular velocity at the bottom of the swing independent of the disk's mass? Building a second pendulum/mass combination may be helpful here.

There's more on the next page!

4. Discussion: attach a typewritten, thoughtful discussion of your findings from your exploration in Part 3 of the worksheet.

Attach a snapshot of your Working Model simulation to this worksheet using the screen capture utility – do not use the Working Model print feature.