Lab 3 - Spring Mass Damper System

Overview

In this lab we will be demonstrating a physical 2 degree of freedom spring mass damper system. During the demonstration, the system will record the experimental data. After observing the short demonstration and saving the experimental data, we will then model the physical system within Simulink. Lastly, we will compare the simulated output to the experimental results and use the Parameter Estimation feature within the "Optimization Toolbox" to refine the Simulink model parameters to better match the real behavior of the physical system.

Resources Required:
MATLAB
Simulink
Simulink Design Optimization
Optimization Toolbox
Simscape
SMDS_Data.xlsx

Description of the System

The system, as seen in figure 1, is a suspended 2 Degree of Freedom (DOF) spring mass damper system with one input force (gravity, once the system is released from initial position).

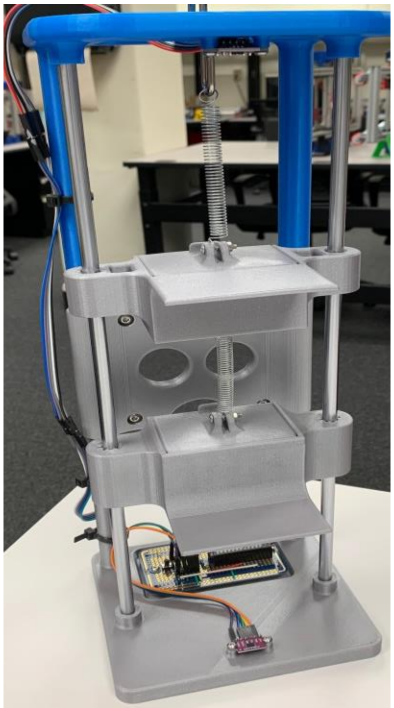

Figure 1: Physical Spring Mass Damper System

Task 1: Physical Model Demonstration and Data

For this task, the TA will perform a brief demonstration of the physical spring mass damper system.

NOTE: A video of the demonstration can also be viewed with following link,

After the demonstration, if you have not done so already, retrieve the data file titled "SMDS_Data.xlsx" from the lab folder in Canvas.

Open the "SMDS_Data.xlsx" file in Excel, or if you don't have Excel, you can open it in Google Sheets. Take note of the data set. It consists of only three columns of data points. The first column is the time in seconds of the data log, the second is the position of mass 1, and the third column is the position of mass 2. The position data is in meters.

1. To exercise good practice and provide yourself clarity in reading the data, add headers to the columns of the data. It is also good practice to include the unit's abbreviation for the column in parenthesis after the header.
2. To get a visual sense of the data, create a "Scatter with Smooth Lines" plot of it. Be sure to include a proper title, legend, and x and y axis labels with units.

Now you have a plot of the experimental data and know the behavior of the system. This also lets you know how the Simulink output should appear and compare to.

To show completion of this task, save your formatted Excel data and plot and show the TA.

Task 2: Modeling Spring Mass Damper System using Simscape

For task 2, we will be modeling the physical spring mass damper system using Simscape. Create the system diagram to look like it is shown in figure 2.

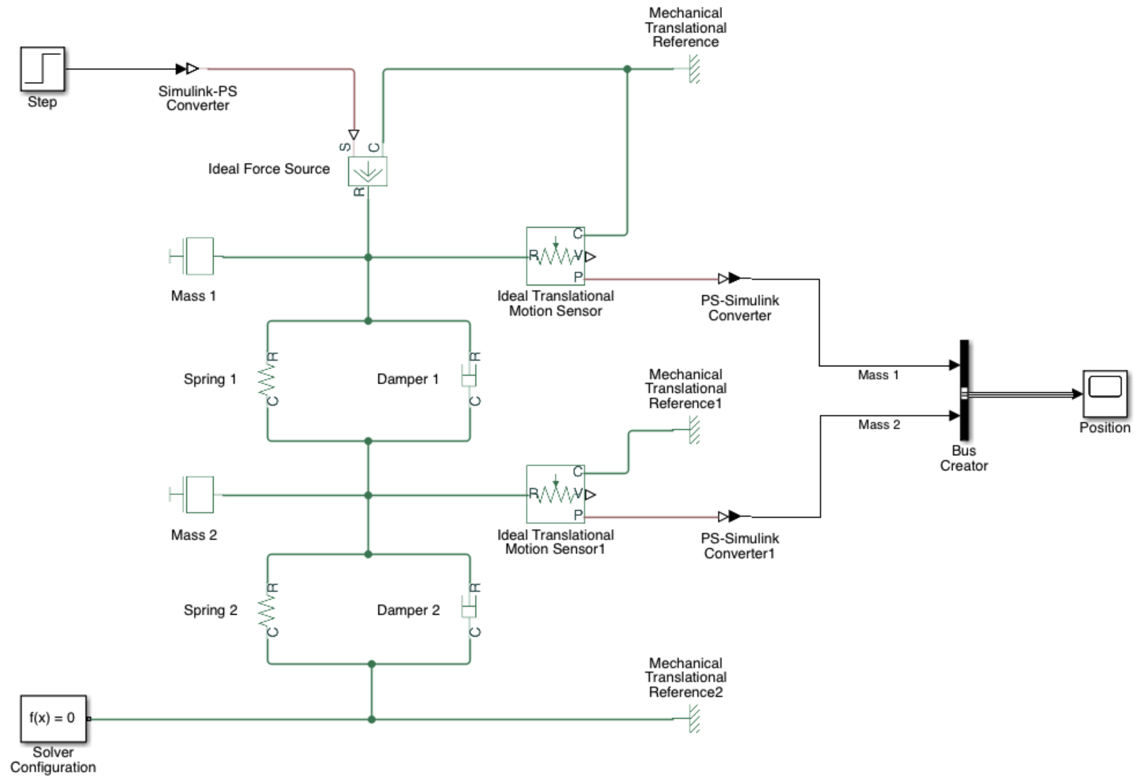

Figure 2: Spring Mass Damper System using Simscape

1. Once you have all the blocks placed and connected, you will need to define some variables that will be used for the final step value, spring rate, and damper coefficient parameters. Navigate to the "Model Workspace" and define the following MATLAB variables.
   - y = 2
   - k1 = 150
   - k2 = 75
   - b1 = 5
   - b2 = 0.5

NOTE: These will also be the parameters that we will later run the parameter estimation tool on to determine what they should be in order for the Simulink model to match more closely to the physical system.

2. Now, update the appropriate blocks with these defined parameters
    - Step time = 0.2 seconds
    - Step final value = y
    - Spring 1 rate = k1 N/m
    - Spring 2 rate = k2 N/m
    - Damper 1 coefficient = b1 N/(m/s)
    - Damper 2 coefficient = b2 N/(m/s)

3. Some constant parameters to the system must also be defined. The masses, their initial positions, and the deformation of the springs are all constants to the physical model and were determined by physically measuring them. Thus, our simulation model should reflect as such.
    Please update these parameters as follows (be mindful of the units):
    - Mass 1 = 0.207 kg
    - Mass 2 = 0.308 kg
    - Mass 1 initial position = 100 mm (Ideal Translational Motion Sensor)
    - Mass 2 initial position = 270 mm
    - Spring 1 deformation = 10 mm (under "Initial Targets")
    - Spring 2 deformation = 20 mm (under "Initial Targets")

NOTE: The initial position parameter is found within the "Ideal Translational Motion Sensor" block and the deformation parameter is found within the "Translational Spring" block, under the "variables" tab. Leave the priority for the deformation parameter set to "High" for both springs.

4. Now, open the "Model Configuration Parameters" window by clicking on the "Modeling" tab at the top of the Simulink ribbon, then clicking the "Model Settings" button within the ribbon.
5. In the "Configuration Parameters" window, be sure you are on the "Solver" tab from the left side pane. Here, you need to change the following:
    - Stop time: 4.5 (seconds)
    - Solver: ode23t (mod.stiff/Trapesoidal)
    - Max step size: 0.2 (seconds)

    For reference, the window with the changes should look like it does in figure 3.

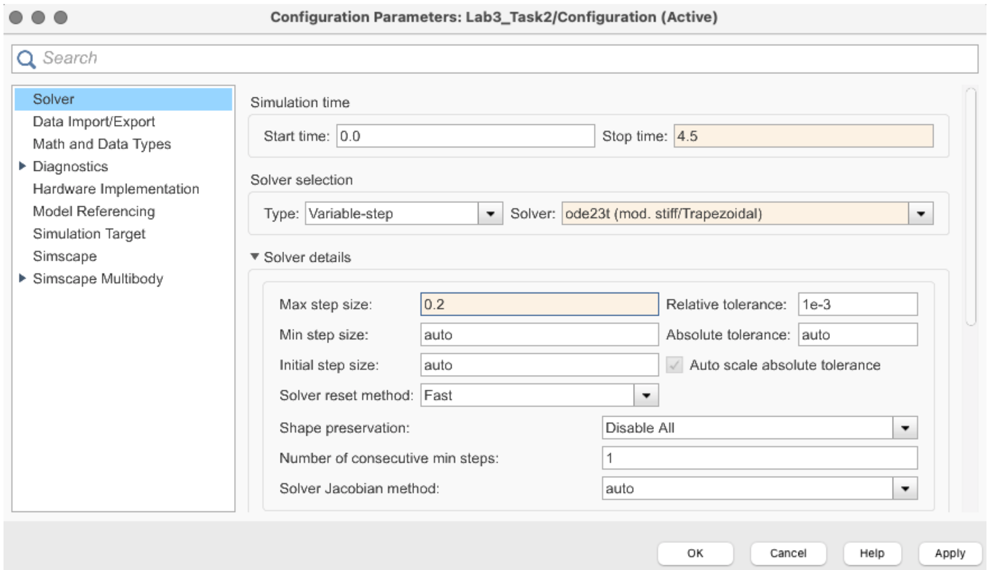

Figure 3: Configuration Parameters Window

6. Run the simulation and ensure that the position scope shows oscillations in the output. The output should look similar to the physical model's plot in Excel.
7. Format and save the block diagram, and the position plot appropriately and include them in your report.

NOTE: Be sure to do this now, as once you run the parameter estimation tool in the next task, the plot will alter. This is because the values for the variables you defined in steps 1 and 2 will change so that the Simulink model's plot fits better to the physical model's plot.

To show completion of this task, save your formatted scope plot and show the TA.

Task 3: Parameter Estimation using Experimental Data

In this task, we will import the physical system's data from task 1 into Simulink. With the data imported, we can then run the parameter estimator to calibrate and determine what the values need to be for each of the variable parameters, in order for the Simulink model to more accurately represent the physical model.

1. To access the Parameter Estimator tool, click on "APPS" tap at the top of the Simulink ribbon. Then click on the "Parameter Estimator" tool icon as shown in figure 4.

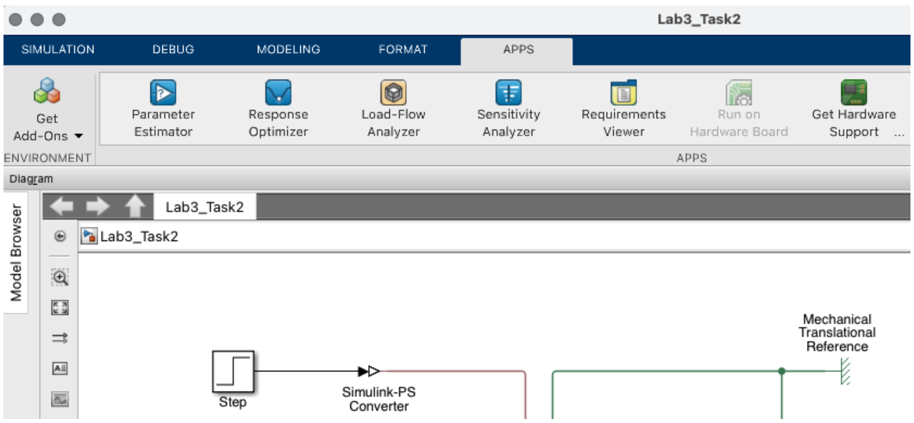

Figure 4: Parameter Estimator App Location

2. We will now create a new experiment in the parameter estimator. Click on the "New Experiment" icon within the ribbon of the "PARAMETER ESTIMATION" tab.
3. Click on "Select Signals" of the newly opened "Edit Experiment: Exp" window.
4. Once, the "Select Outputs" window opens, you will need to add the Mass 1 and Mass 2 outputs to the output table. Do this by selecting the Mass 1 and Mass 2 output arrows in the block diagram, as shown in figure 5. The signals should then be added to the output table for the experiment as shown in figure 6.

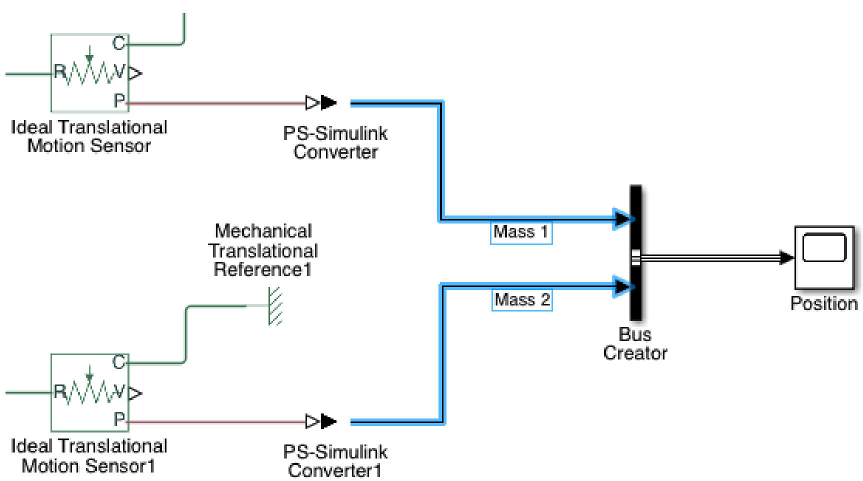

Figure 5: Mass 1 & 2 Output Signals

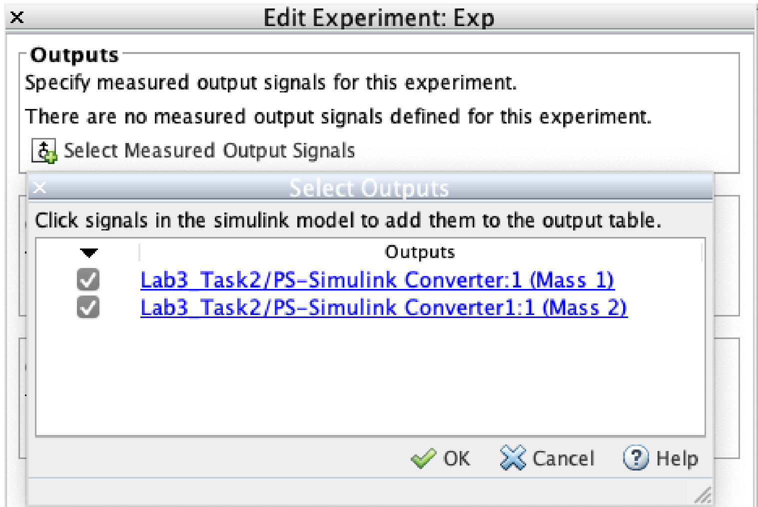

Figure 6: Select Outputs Window

5. After adding the signals to the output table, click the “OK” button in the “Select Outputs” window.
6. Now, we will need to import the experimental data from the physical system. The data for both Mass 1 and Mass 2 will need to be imported. We will start with Mass 1. In the “Outputs” section, click on the green download arrow icon, as shown in figure 7.

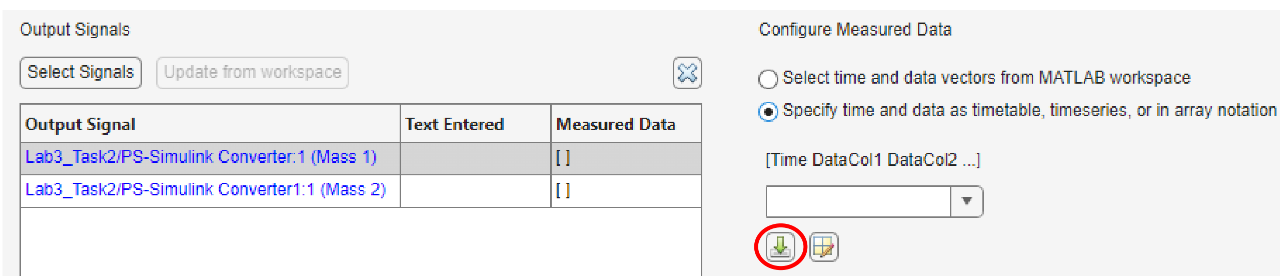

Figure 7: Import Data Button for Output Signals

7. After the file explorer window opens, navigate to and open the Excel file you saved with the experimental data, from task 1.
8. In the import selection window, select the data set for Mass1, that is columns A & B only. Be sure the entire data set down to the 4.5 seconds is selected. Then click on the “Import Selection” button in the top ribbon, as shown in figure 8.

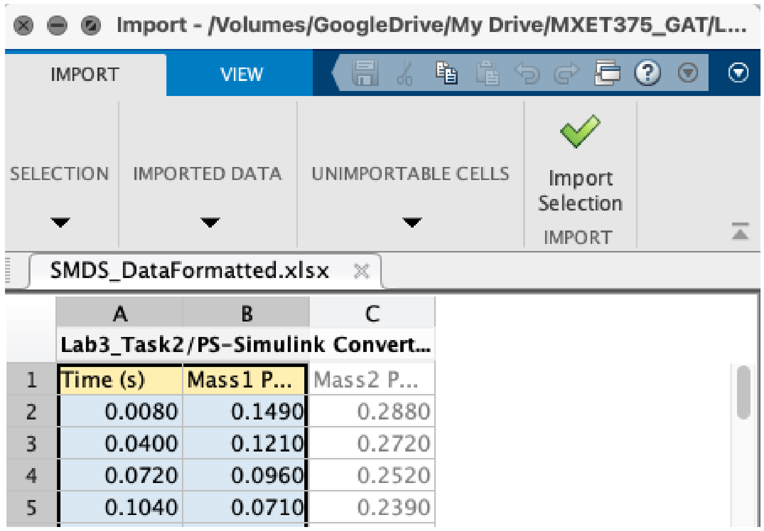

Figure 8: Mass 1 Data Import Selection

9. Repeat steps 6 through 8 and import the experimental data for Mass2. If it doesnt work, try saving the data separately into 2 new excel files. For Mac, try saving the file as .csv
10. After the data is imported, we will need to define the parameters we want to modify upon executing the estimate command. Under the "Parameters" section, click on the "Select Parameters" button.
11. Next, select all the parameters we defined within the model. That is variables b1, b2, k1, k2, and y. These are "continuous" variables. This is shown in figure 9.

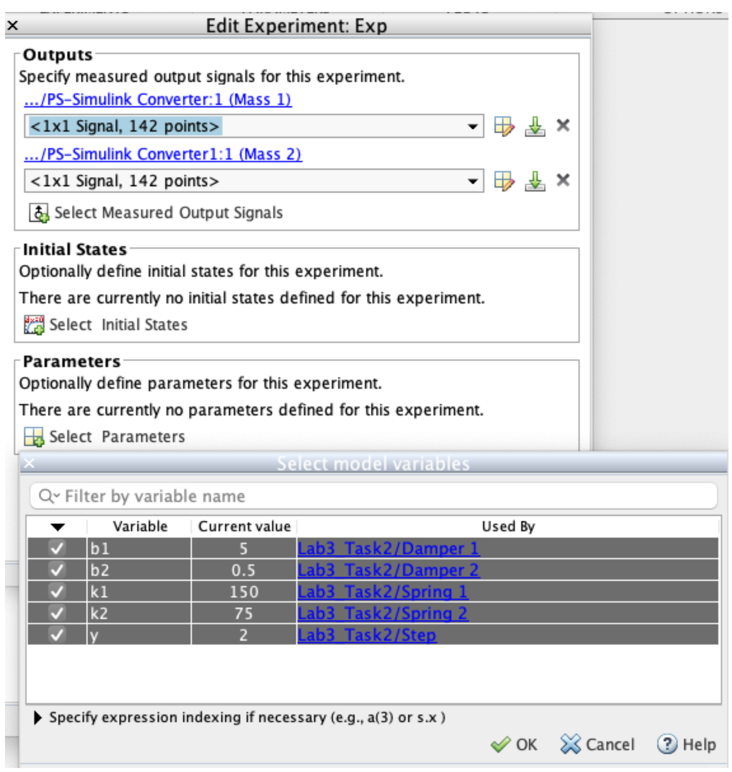

Figure 9: Parameter Selection

12. Click the “OK” button at the bottom of the “Select model variables” window.
13. Finally click the “Plot & Simulate” button at the bottom of the “Edit Experiment: Exp” window. The Parameter Estimator will plot both the experimental/measured and simulation data for both Mass 1 and Mass 2. The result should look as it does in figure 10.

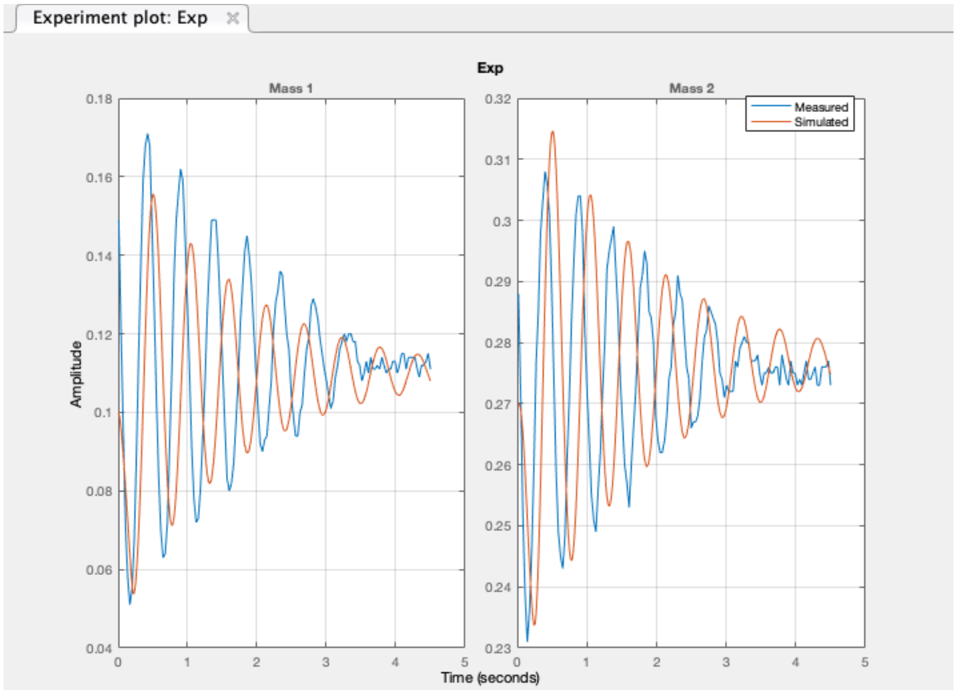

Figure 10: Parameter Estimator Plots Before Estimation

NOTE: The plots produced are just the plots of the experimental data and the simulation with the parameters set to the values defined in task 2. This is to show the comparison between the two prior to running the estimate command to calibrate the values. Note that the results are similar but not exactly the same.

14. Capture a screenshot of the plots like that of figure 10 and include it in your report.
15. Now we will run the estimate command to calibrate the Simulink model and determine what the variable’s values should approximately be in order for the simulation to match the physical system. Click on the “Estimate” button on the right side of the “PARAMETER ESTIMATION” ribbon.
16. It will take several minutes of iterative calibration to finish the estimation. You can watch the simulated plots begin to converge on the measured plots during the estimation. Once it is complete, capture a screenshot of the updated plots and include it in your report.
17. Return to the block diagram of the Simulink model and open the Model Workspace. Notice that the values for the variables have changed. Note the new values to 4 decimal places for each of the variables and include them in a table in your report.
18. Lastly, run the simulation once more and view the scope output. Note the slight change from the original scope output. Save this updated plot and include it in your report.

To show completion of this task, show the TA the parameter estimation plots after the estimation and the updated scope output plot.

Post-Lab Questions

1. What are the final values (to 4 decimal places) for all the estimated parameters from the system (y, k1, k2, b1, b2)?

2. Go back into the block diagram and change mass 1 to equal 0.350 kg and mass 2 to equal 0.500 kg. Do not change the values of the estimated parameters from the previous estimate. Return to the parameter estimator, create a new experiment as you did in task 3 and re-run the estimator. Note: This estimation will take longer than the first estimation. What are the new values for the parameters? Rerun the scope and paste the graph.

3. Based on Question 2, what happened to the position scope output? Can we reproduce the same dynamic response (plot) even if the mass is different? Then, why might we choose not to allow the estimator to manipulate the mass along with the other parameters?

4. Why did we change the simulation stop time to 4.5 seconds in step 5 of Task 2?

5. The experimental system exhibits some damping despite there not being a traditional translational dampener. What is causing the damping effect?

6. Why is there a difference between the starting position of Task 2 from Task 1? Can we make them similar?