MXET 375
Applied Dynamic Systems

Multidisciplinary
Engineering Technology
COLLEGE OF ENGINEERING

LABORATORY # 5

Importing Solid Model Parts & Assemblies

Submission Date: 10/03/2024

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Introduction

The purpose of Lab 5 is to expand an individual's knowledge on how to import solid model parts and assemblies created in CAD software, such as SolidWorks or Fusion 360, into a Simulink model for simulation using Simscape Multibody. The objectives include gaining an understanding of how to integrate CAD models into dynamic simulations, exploring the effects of geometry on physical behavior, and learning to adjust and configure model parameters such as damping, inertia, and spring stiffness to observe realistic mechanical system behavior. Task 1 focuses on importing asymmetric dumbbell-shaped solid models into a pendulum system and analyzing the oscillatory behavior of each model. Task 2 involves importing a multibody robotic assembly, correcting its performance through joint adjustments, and using a scope to observe the motion of the robot's middle joint as modifications are applied. By the end of the lab, the individual should have a solid grasp of importing CAD models, setting up dynamic simulations, and interpreting mechanical system behavior using Simulink, Simscape Multibody, and MATLAB.

Procedure & Lab Results

This lab has two tasks total. Each task includes a detailed description of the setup, procedure, results, relevant figures, and discussion focusing on developing a better understanding and interpretation of what the results mean and how they were derived.

Task 1

Task 1 focuses on importing asymmetric dumbbell-shaped solid models into a pendulum system and analyzing the oscillatory behavior of each model. The purpose of this task is to expand the understanding of creating, modeling, simulating, and analyzing basic pendulum systems. The pendulum system is a basic model where a predefined block functions as both the world frame and the fulcrum point for the imported dumbbell solid models. Two distinct variations of the dumbbell will be utilized to observe how small differences in geometry influence their physical behavior as pendulums. These variations can be seen in Figure 1, and their comparative motion will provide insight into how slight modifications to the geometry can alter the pendulum dynamics.

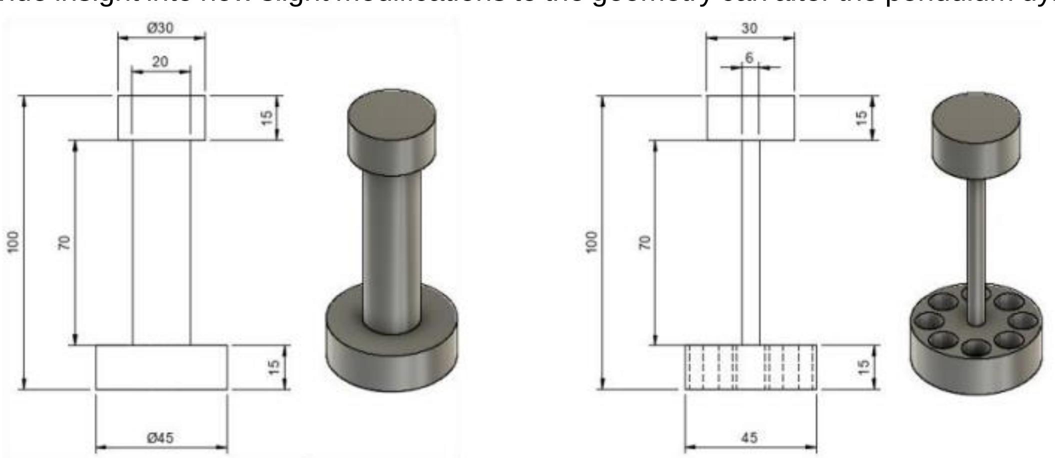

Figure 1: Dumbbell Models One (Left) and Two (Right) for Pendulum System [1]

To begin Task 1, first retrieve and open the required files. Download the "Pendulum.zip" folder, extract its contents, and then open the SimplePendulum.slx file in Simulink. Once the model is open, run an initial simulation to observe the pendulum in the Mechanics Explorer. Right-click the model in the Mechanics Explorer, and select both "Show Frames" and "Show COMs" to display the frames and centers of mass. The result of this can be seen in Figure 2.

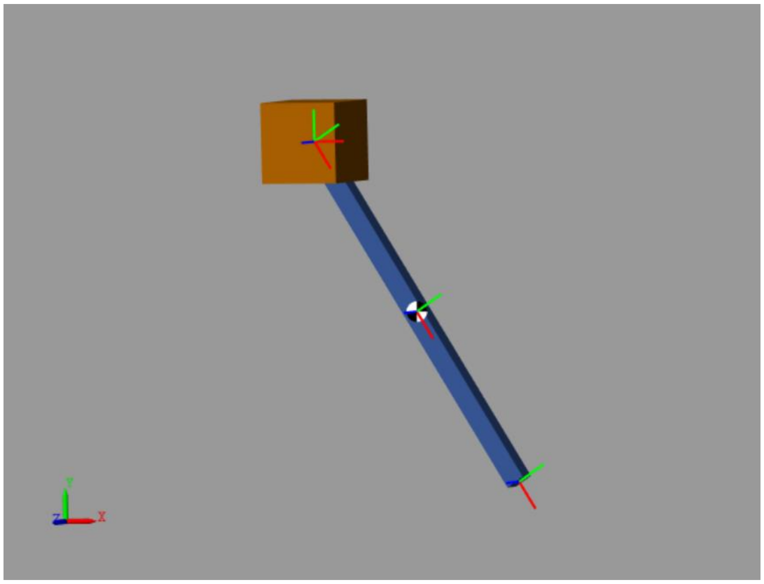

Figure 2: Simple Pendulum Within Mechanics Explorer Simulation Window [1]

Next, add damping to the system by opening the "Revolute Joint" block within the Simulink model. Expand the "Internal Mechanics" tab and set the damping coefficient to 0.001 N*m/(rad/s). Re-run the simulation to observe the damped behavior of the pendulum, noting how the movement changes with the addition of damping. Afterward, replace the default pendulum model with a custom dumbbell. To do this, access the "Simple Link" subsystem, delete the "Solid," "Rigid Transform1," and "Conn2" blocks, and insert a "File Solid" block. Connect the new block to the "Rigid Transform" block, and select the dumbbell.STEP file from the extracted "Pendulum.zip" folder. Set the custom density in the "File Solid" block to 1000 kg/m^3 and press F5 to update the visualization, ensuring the new model is rendered correctly. The next step involves adjusting the dumbbell's frame and linking it to the world frame. Open the "File Solid" block, navigate to the "Frames" tab, and create a new frame based on the circular surface of the dumbbell. Set the axes as follows: the primary axis should be aligned with +Z and the secondary axis with +X. These adjustments should align the dumbbell with the world frame. In the "Rigid Transform" block, configure the axis to +Z and set the offset to -4 cm. Check the Mechanics Explorer to ensure that the dumbbell is properly positioned after updating the model. Now, add a scope to observe the pendulum’s behavior. In the "Revolute Joint" block, enable the "Position" sensor under the "Sensing" tab. Add a "PS-Simulink Converter" and a "Scope" block, and connect them to the "Position" output. The setup configuration of the required block diagrams to produce the correct plots, with all block names, and the annotated connection line names, can be seen in Figure 3 and Figure 4.

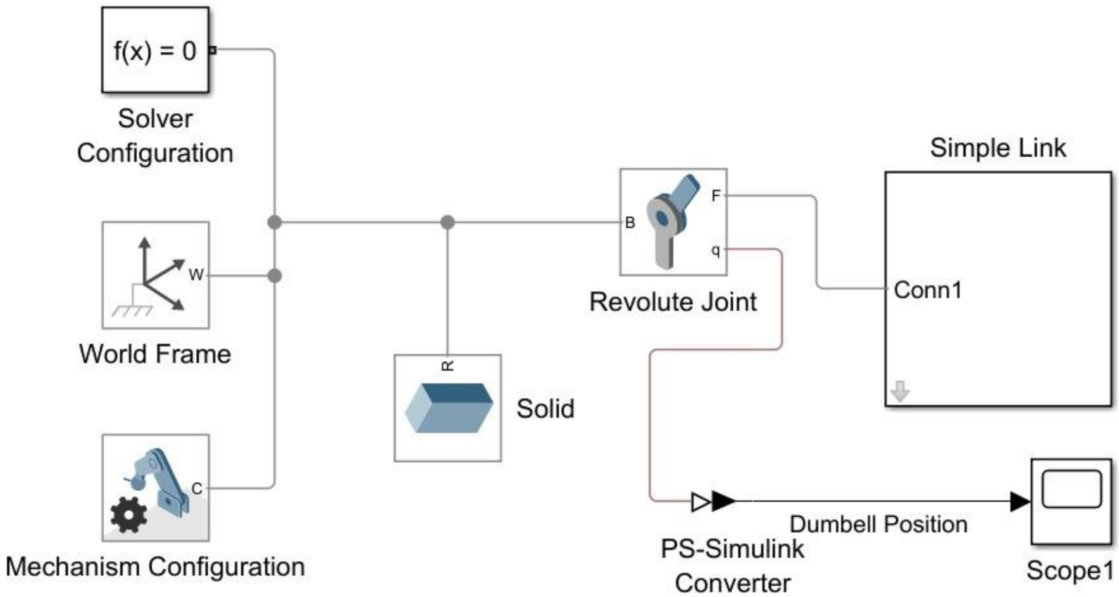

Figure 3: Simple Pendulum Model Complete Block Diagram

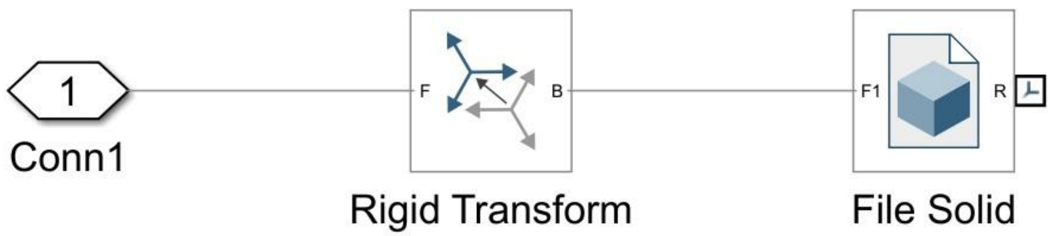

Figure 4: New Frame Connection in Simple Link Subsystem

After setting the simulation time to 5 seconds the final step is to run the system, observe the pendulum's motion in the scope, and format the result to the specified requirements described in Lab 1. The resulting plot and mechanics explorer view can be seen in Figure 5 and Figure 6 respectively.

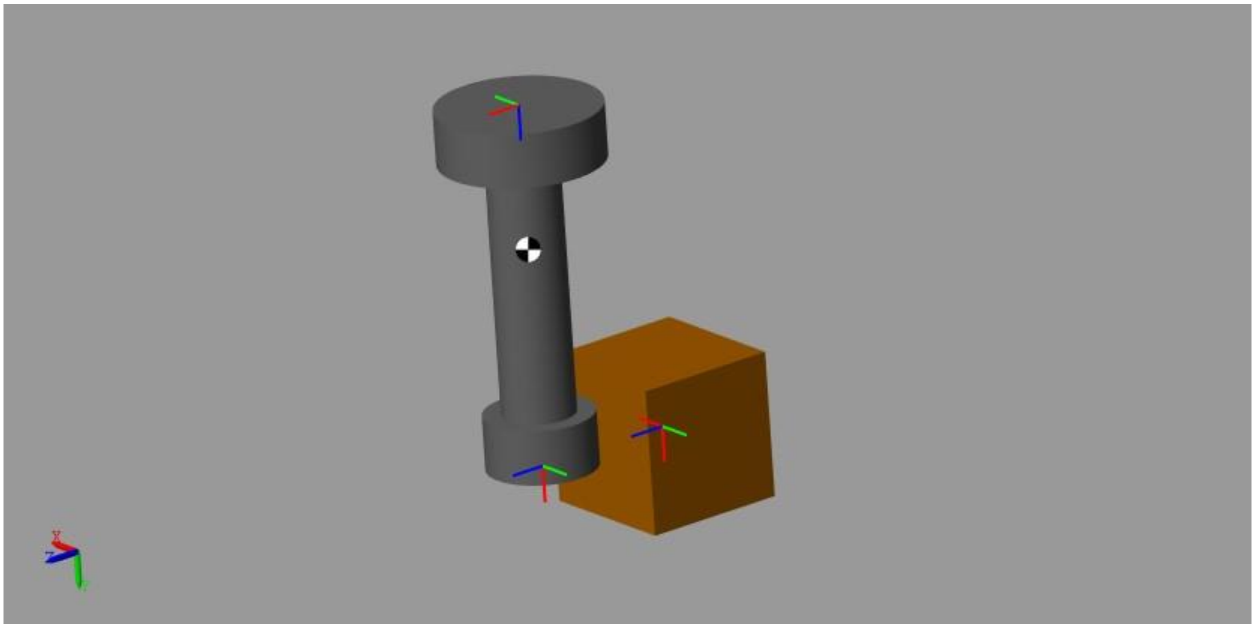

Figure 5: Dumbbell One Pendulum Model Within Mechanics Explorer Simulation Window

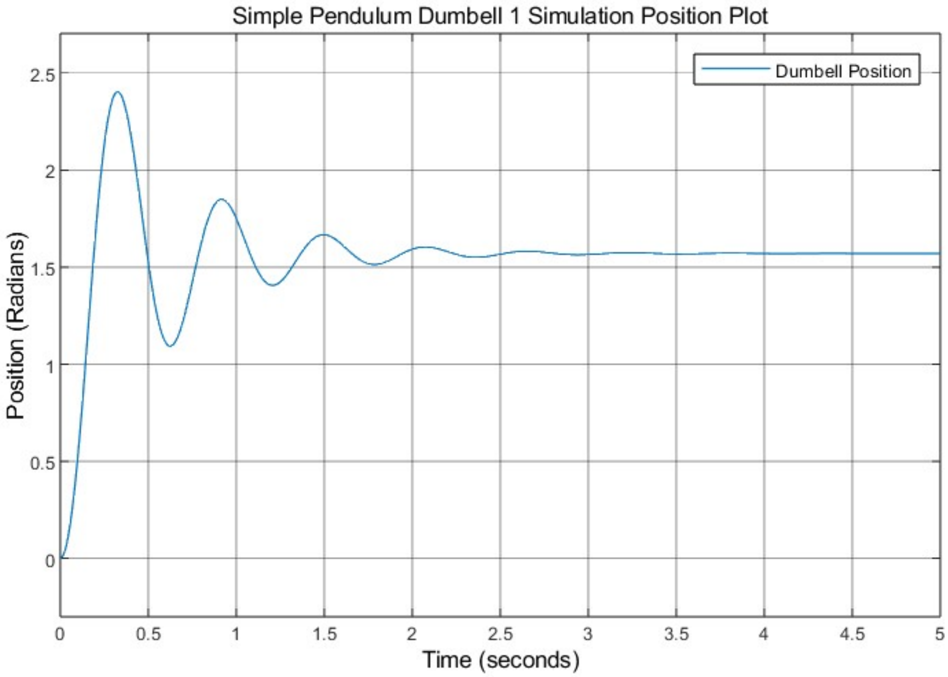

Figure 6: Dumbbell One Pendulum Model Position Vs. Time Simulation Plot

Finally, replace the dumbbell model with the second version by selecting the dumbbell2.STEP file in the "File Solid" block. Re-run the simulation to observe how this second dumbbell model behaves and format the result to the specified requirements described in Lab 1. The resulting plot and mechanics explorer view can be seen in Figure 7 and Figure 8 respectively.

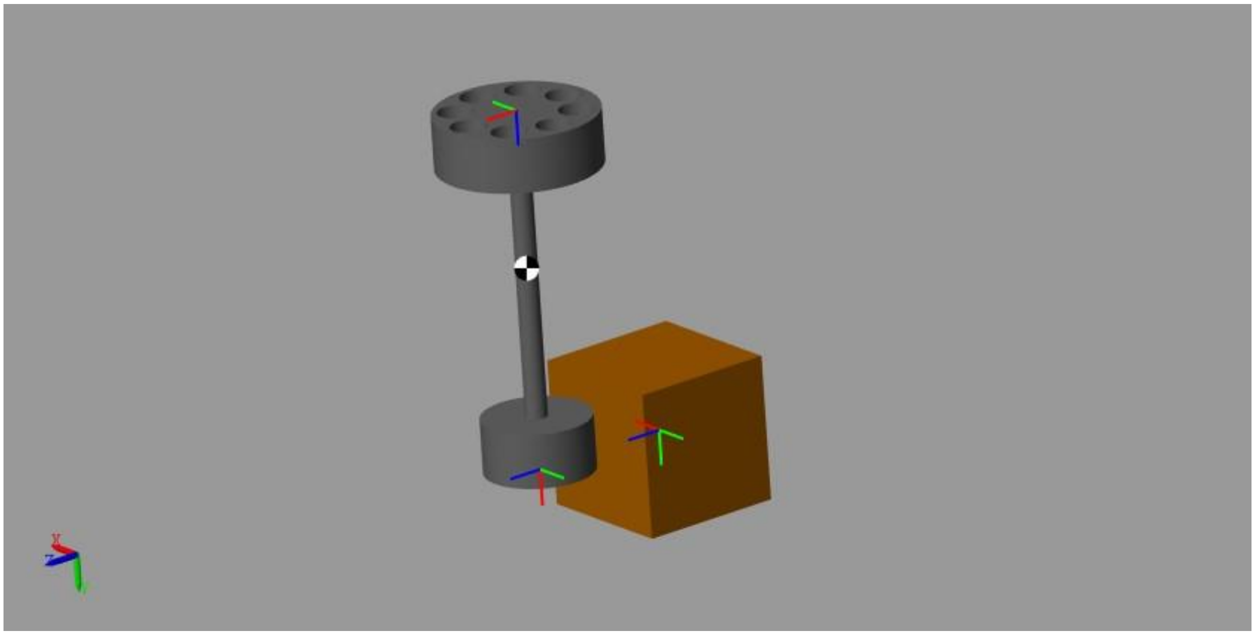

Figure 7: Dumbbell Two Pendulum Model Within Mechanics Explorer Simulation Window

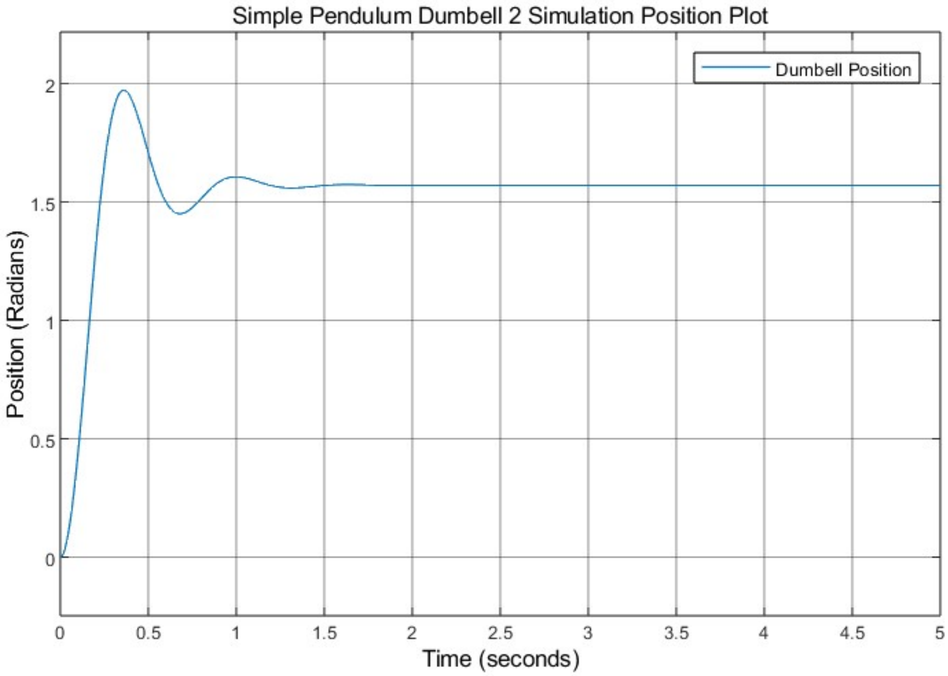

Figure 8: Dumbbell Two Pendulum Model Position Vs. Time Simulation Plot

The analysis and comparison of the two dumbbell pendulums from the simulation reveal significant differences in their oscillatory behavior due to variations in geometry. Dumbbell One, which is thicker, exhibits oscillations that last approximately 3 seconds before damping to less than 10% of the initial amplitude. Its position plot illustrates a gradual decrease in amplitude, indicating slower energy dissipation. In contrast, Dumbbell Two, the thinner pendulum, experiences a quicker cessation of oscillations, lasting around 1.5 seconds and similarly dropping below 10% of the initial amplitude. The plot for this pendulum shows a more rapid decay in amplitude compared to the thicker model. The physical properties of each dumbbell significantly impact their motion. The thicker pendulum has a greater moment of inertia due to its larger mass and extended center of mass, which leads to higher resistance to changes in motion and consequently longer oscillation periods. On the other hand, the thinner dumbbell has a smaller moment of inertia, allowing for quicker oscillation decay. Additionally, the position of the center of mass influences the dynamics. The thicker pendulum’s higher center of mass results in a slower response to gravitational forces, while the thinner model, with its lower center of mass, responds more rapidly to external forces. Damping effects also play a crucial role in the behavior of the pendulums. The thicker pendulum experiences less damping because of its higher moment of inertia, enabling it to retain energy longer and thus extend the duration of its oscillations. In contrast, the thinner pendulum, with a higher damping effect, loses energy more rapidly, leading to a quicker cessation of motion. Slight differences in the geometry of the dumbbell models significantly influence their oscillatory behavior as pendulums. The thicker dumbbell's larger mass and center of mass result in more prolonged oscillations, while the thinner dumbbell shows faster damping and decay of motion. These results emphasize the importance of understanding physical properties in pendulum dynamics, illustrating how design changes can lead to varied performance in mechanical systems.

After viewing the scope from the first thicker pendulum (dumbbell.STEP) it can be concluded that it takes about 3 seconds before the oscillations die out (<10% of initial magnitude). After viewing the scope from the second thinner pendulum (dumbbell2.STEP) it can be concluded that it takes about 1.5 seconds before the oscillations die out (<10% of initial magnitude). The change in duration for the oscillations between the two dumbbell pendulums is caused by difference in MOI (Moment of Inertia) and the difference in COM (Center of Mass) (L).

Because the first pendulum is thicker it has a larger mass and center of mass. Therefore, based on the understanding of the directly proportional relationship between Moment of Inertia (I), Mass (m), and Center of Mass (L) as shown in Equation 1, the Inertia increases and dampening decreases.

$$I = m * L^2 \tag{1}$$

Whereas the thinner pendulum has a smaller mass and center of mass therefore the Inertia decreases and the damping increases. Based on this it can be concluded that the dumbbell pendulum with more damping and less oscillations is the thinner pendulum and the dumbbell pendulum with less damping and more oscillations is the thicker pendulum. This conclusion is confirmed by the resulting position plots for these dumbbells previously shown.

Task 2

Task 2 involves importing a multibody robotic assembly, correcting its performance through joint adjustments, and using a scope to observe the motion of the robot's middle joint as modifications are applied. The purpose of this task is to expand the understanding of creating, modeling, simulating, and analyzing basic robotic systems. The multibody robotic assembly system consists of a four-linked arm with a tube-shaped end-effector. It includes three HEBI module actuators arranged in series, each responsible for driving motion at the joints. This configuration allows the actuators to control movement, ultimately directing the motion of the tube end-effector. The model representing this system can be seen in Figure 9.

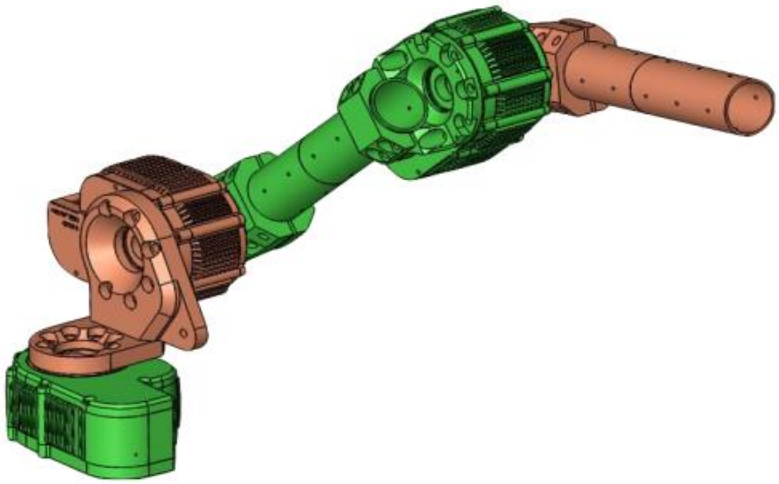

Figure 9: HEBI Multibody Robot Assembly [1]

To begin Task 2, import the multi-body robot assembly into Simulink. Start by opening MATLAB and navigating to the downloaded provided folder with the "multibodyRobot" files. In the command window, type smimport('multibodyRobot.xml') and press Enter to load the model. This will open the Simulink block diagram for the multi-body assembly. Next, open the level1_1_RIGID sub-assembly in the block diagram and access the "Solid" block. Under the Graphic > Visual Properties section, change the Color value to [0 0.8 0]. Repeat this same process for the "Solid" block in the level3_1_RIGID subsystem to differentiate the different parts of the assembly by color. After adjusting the visuals, open the Revolute block in the main block diagram and set the State Targets > Specify Position Target to 0 degrees. Do the same for the "Revolute1" and "Revolute2" joints. This ensures that the joints start in a stable position during the simulation. Now, update the simulation settings by opening the Model Settings. Set the Stop time to 3 seconds, the Solver to ode23t (mod.stiff/Trapezoidal), and the Max step size to 0.01 seconds. These settings will help manage the complexity of the model during the simulation. To observe the behavior of the middle joint, open the "Revolute1" block and add a Velocity Sensor. Then, connect a PS-Simulink Converter and a Scope block to track the joint's angular velocity during the simulation. The setup configuration of the required block diagram to produce the correct plots, with all block names, and the annotated connection line names, can be seen in Figure 10.

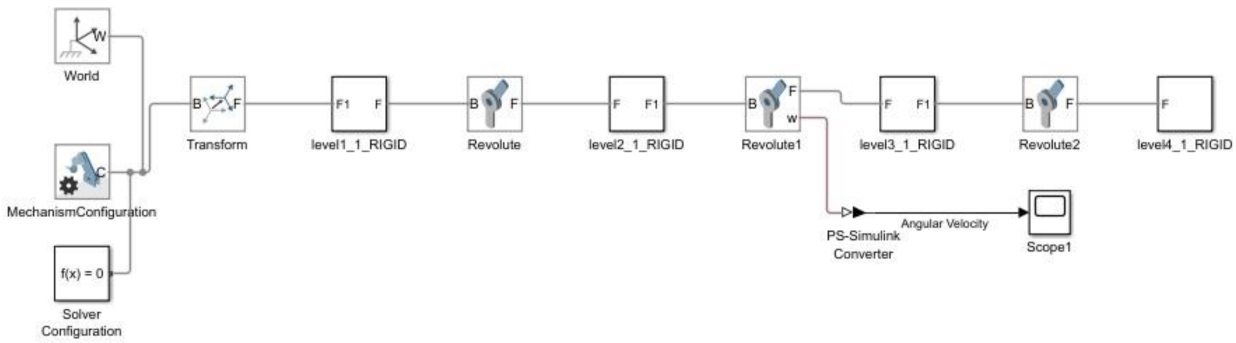

Figure 10: Multibody Robot Complete Block Diagram

After setting this up, change the gravity settings in the Mechanism Configuration block by entering [0 0 -9.81] into the Gravity field to simulate Earth's gravitational pull. Once that is complete the next step is to run the system and format the result to the specified requirements described in Lab 1. The resulting plot can be seen in Figure 11.

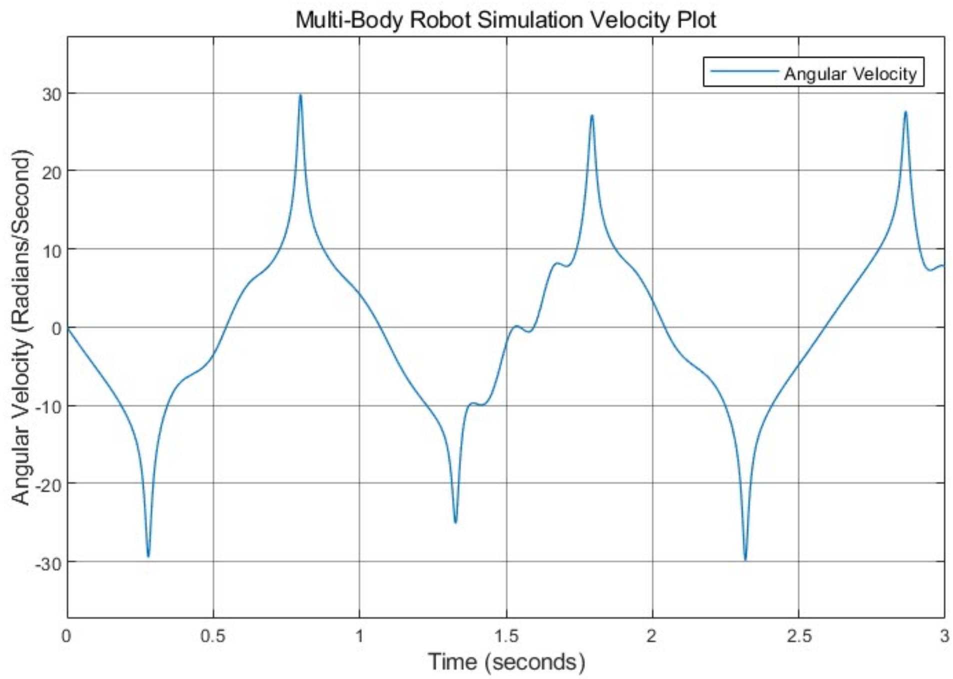

Figure 11: Multibody Robot Without Stiffness or Damping Angular Velocity Vs. Time Simulation Plot

Next, return to the Revolute Joint blocks and apply spring stiffness values. Set Joint 1 and Joint 2 to 1 Nm/rad, and set Joint 3 to 0.1 Nm/rad. Once that is complete the next step is to run the system and format the result to the specified requirements described in Lab 1. The resulting plot can be seen in Figure 12.

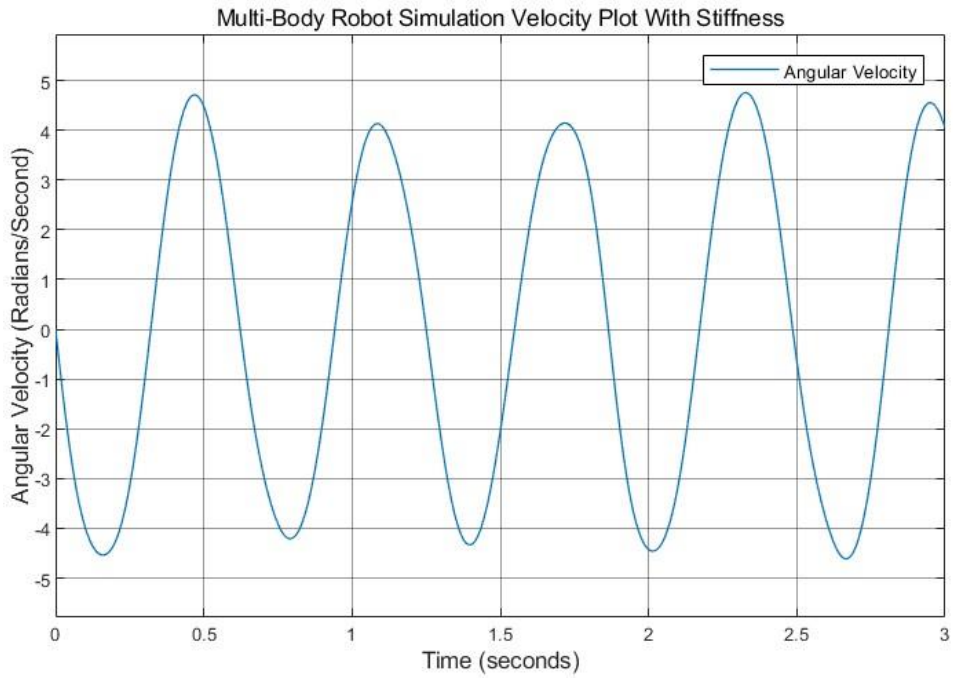

Figure 12: Multibody Robot with Stiffness Angular Velocity Vs. Time Simulation Plot

Once the stiffness values are applied, set the damping coefficients. For Joint 1 and Joint 2, enter a value of 0.05 Nm/(rad/s), and for Joint 3, enter 0.005 Nm/(rad/s). Once that is complete the next step is to run the system and format the result to the specified requirements described in Lab 1. The resulting plot can be seen in Figure 13.

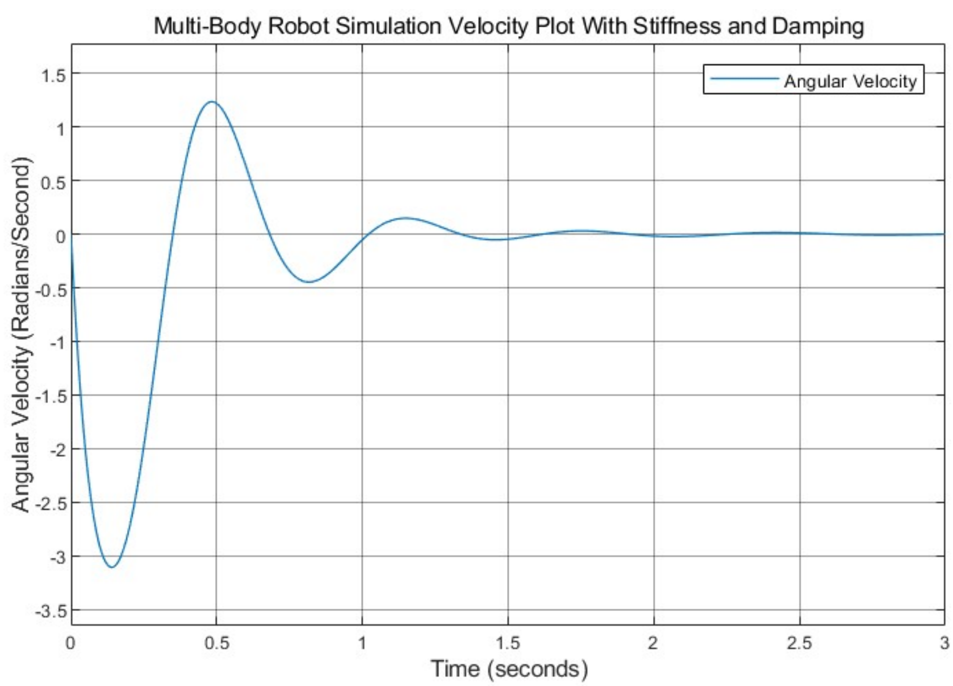

Figure 13: Multibody Robot with Stiffness and Damping Angular Velocity Vs. Time Simulation Plot

The final step is to open the Mechanics Explorer and take two screenshots of the model, one at 0.0 seconds and another at 3.0 seconds, to capture the robot's start and end positions ensuring that the view remains the same for both screenshots. These screenshots can be seen in Figure 14 and Figure 15.

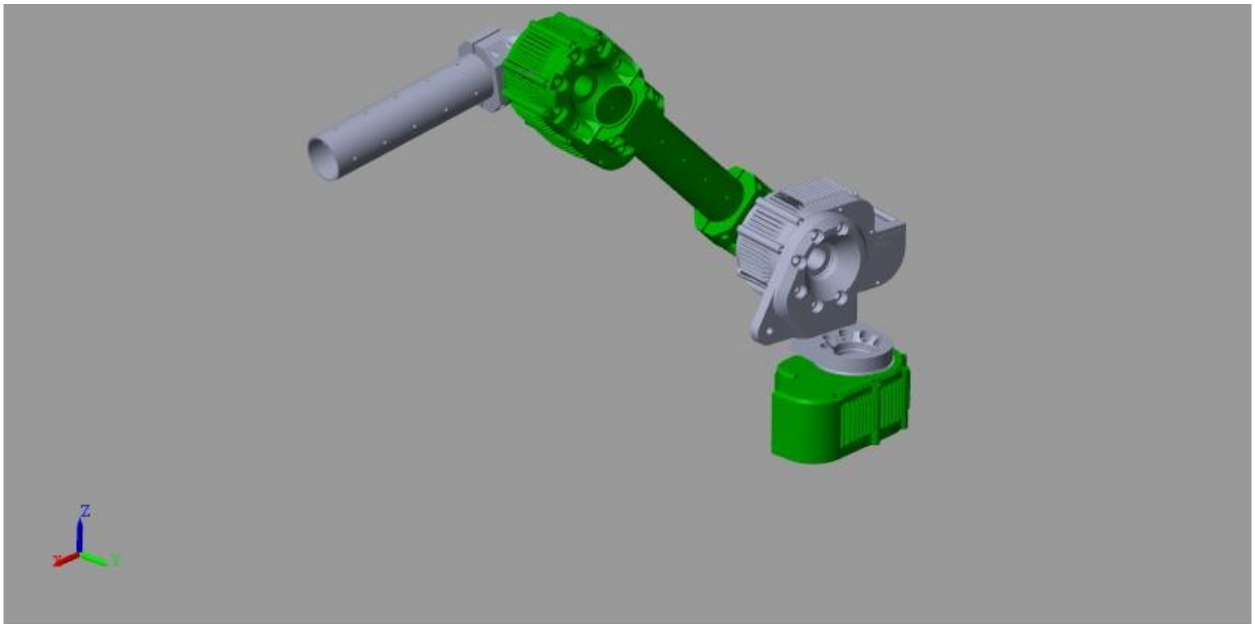

Figure 14: Multibody Robot Within Mechanics Explorer Simulation Window Starting Position at 0 Seconds

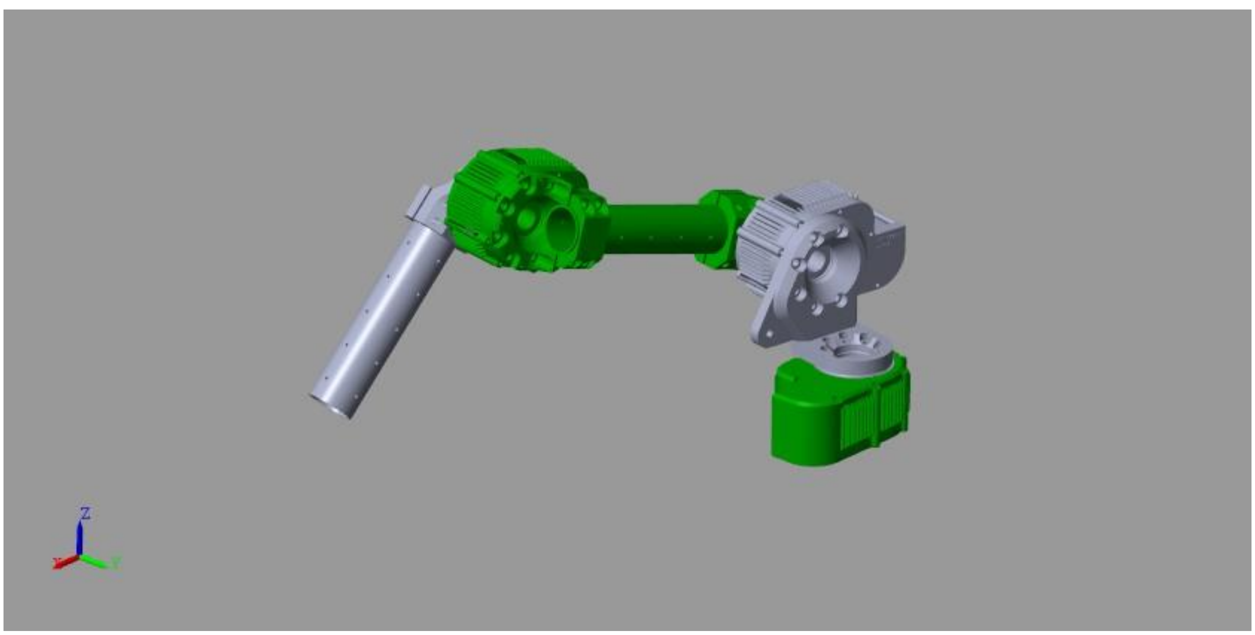

Figure 15: Multibody Robot Within Mechanics Explorer Simulation Window Final Position at 3 Seconds

The first plot, representing the system without stiffness or damping, shows a highly erratic and unstable behavior. The angular velocity fluctuates dramatically, reaching peaks of over 30 radians per second and plummeting to negative values below -30 radians per second. These rapid and chaotic oscillations indicate that the system lacks any form of control over the joint motion. The absence of stiffness and damping leads to unrestrained joint movements, where the actuators react to the slightest changes in initial conditions, causing extreme velocities. This uncontrolled nature points to the system being highly reactive and unstable without any mechanisms to restrain or regulate its movement. In the second plot, where stiffness is applied to the joints, the system's behavior becomes more controlled. The angular velocity now oscillates in a smoother, sinusoidal pattern with values between -5 and 5 radians per second. This is a significant improvement compared to the first plot, where velocities were much higher and more chaotic. The introduction of stiffness provides a restoring force that resists joint displacement, leading to periodic oscillations. However, without damping, the system continues to oscillate indefinitely because energy is not being dissipated. While stiffness adds control and predictability to the system, the sustained oscillations reflect the absence of damping, which would otherwise temper the joint's movements. In the third plot, where both stiffness and damping are applied, the system achieves stability. The angular velocity initially peaks at around 1.5 radians per second before gradually settling close to zero, indicating that the oscillations are quickly dampened. The presence of damping dissipates the system's energy, preventing sustained oscillations and allowing the system to reach a steady state. This is the most stable configuration, as the combination of stiffness and damping provides both control and energy dissipation. The joint movements are predictable and well-regulated, making the system suitable for applications requiring precise and stable motion control, such as robotics. The first plot illustrates a chaotic and unstable system due to the absence of stiffness and damping. The second plot shows improved control with the application of stiffness, though the lack of damping leads to continued oscillations. The third plot, with both stiffness and damping applied, demonstrates a well-controlled and stable system where oscillations decay over time, resulting in predictable and precise joint movement. The progression across the three plots highlights the importance of carefully tuning mechanical properties like stiffness and damping in robotic systems to achieve desired performance and stability.

Considering the motion of the robot between its starting and ending positions it can be concluded that the units being used for angular velocity in this simulation are radians per second. This is reflected in all of the plots created for this task. After some trial and error with configuring joint parameters to make the motion of the tube end-effector start in a position that is aligned with the Z-axis and end in a position that is parallel to the XY-plane the following table of values was created that can be seen in Table 1.

Table 1: Resulting Parameters of Tube End-Effector After Configuration

	State Position Target (deg)	**Equilibrium Position (deg)**	**Spring Stiffness (Nm/rad)**	**Damping Coefficient (Nm/(rad/s))**
Joint 1	0	0	1	0.05
Joint 2	46	-14	1	0.05
Joint 3	54	69	0.1	0.005

These configured values created the desired motion path of the tube end-effector. The staring position at 0 seconds and final position at 3 seconds of the robot with these parameters is shown in Figure 16 and Figure 17 respectively.

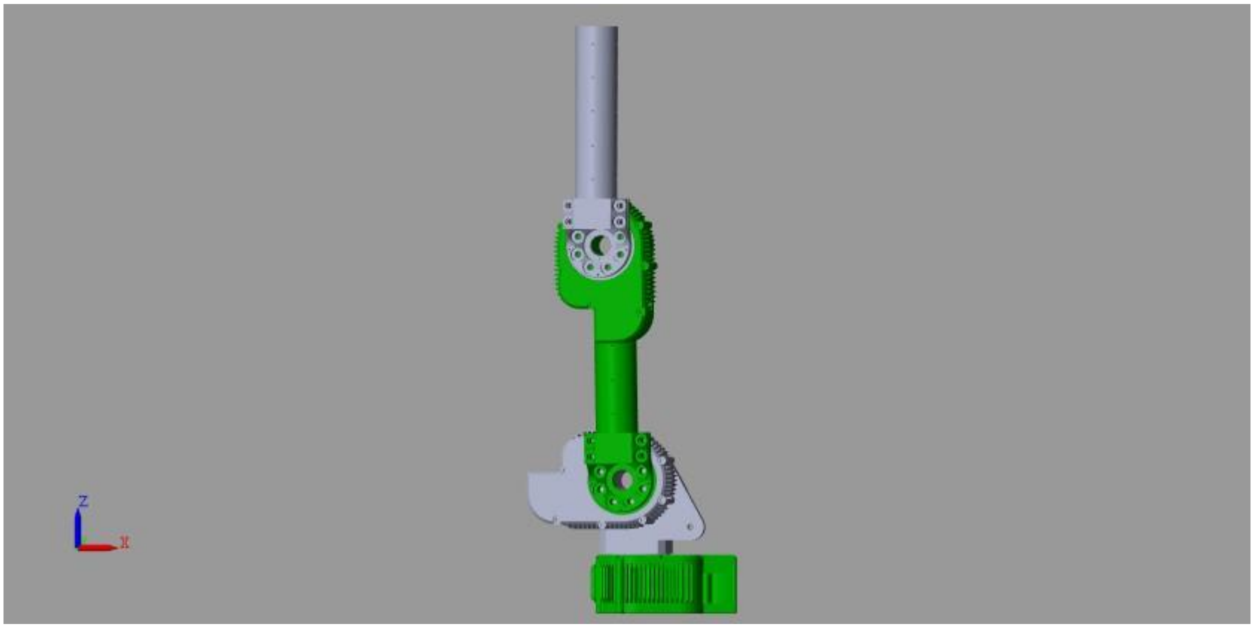

Figure 16: Configured Multibody Robot Within Mechanics Explorer Simulation Window Starting Position at 0 Seconds

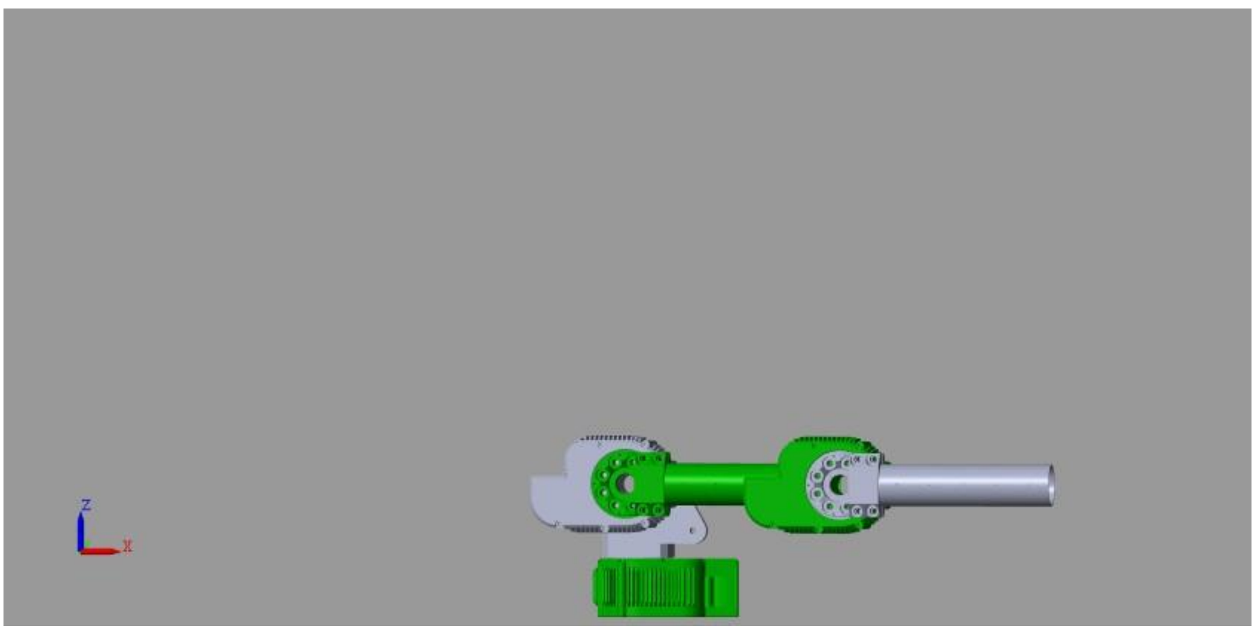

Figure 17: Configured Multibody Robot Within Mechanics Explorer Simulation Window Final Position at 3 Seconds

Conclusion

Lab 5 provided valuable insights into the process of importing solid model parts and assemblies from CAD software into Simulink for dynamic simulations using Simscape Multibody. Through the completion of the lab tasks, key concepts related to the impact of geometry on physical behavior and the importance of adjusting model parameters, such as damping, inertia, and spring stiffness, were emphasized. In Task 1, asymmetric dumbbell-shaped models were imported into a pendulum system to analyze their oscillatory behavior. The results highlighted how variations in geometry significantly influence pendulum dynamics. The thicker dumbbell, with a larger mass and moment of inertia, exhibited longer oscillations due to its increased resistance to motion, while the thinner dumbbell demonstrated quicker damping and faster oscillation decay. This task reinforced the concept that moment of inertia and center of mass play critical roles in determining the oscillatory characteristics of pendulum systems. Task 2 involved the importation of a multibody robotic assembly, where joint parameters such as stiffness and damping were adjusted to correct the system's performance. Initially, without stiffness or damping, the robotic system exhibited erratic and unstable behavior. The application of spring stiffness brought more controlled, sinusoidal motion, while the addition of damping effectively dissipated energy, leading to stable joint movement. This task underscored the importance of properly tuning joint parameters to achieve desired performance and stability in robotic systems. Overall, Lab 5 demonstrated the practical application of integrating CAD models into dynamic simulations, offering a deeper understanding of how mechanical systems respond to changes in geometry, mass distribution, and joint parameters. The lab successfully illustrated how these factors can be manipulated to optimize system behavior, providing valuable skills for future engineering design and analysis.

References

[1] Author not listed, *Texas A&M University MXET375 - Lab 05 - Importing Solid Model Parts & Assemblies*. College Station, TX, USA: Date not listed.
[2] Rex K., *MXET375 - Kyle Rex - Lab Report 4*. College Station, TX, USA: 10/03/2024.