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I. Introduction

This project consists of the modeling and physics simulation of a basic two-legged walking robot. The robot components will be drafted and simulated in with the ADAMS software. These components can also be drafted in other 3D drafting programs and imported into ADAMS, however, this report does not cover that process. To keep the physics of the model as simple as possible, the drafted model must also be composed of simple parts.

Though the robot model will be very simple in comparison to the complexity of the human body, it will demonstrate the basics of bipedal locomotion. This robot takes inspiration from the many designs that already exist of robots that operate in the same manner. By using the ADAMS software, the robot design used in this project can be analyzed more in-depth and allow adjustments to be made if necessary.

II. Setup and Parts Modeling

A. Initial Setup

The first step of this simulation involves opening the ADAMS software and ensuring that the setting for this project are correct. The model name and units of measurement can be changed at the user's discretion. This project will use the standard units of measurement, with millimeters as the unit of length.

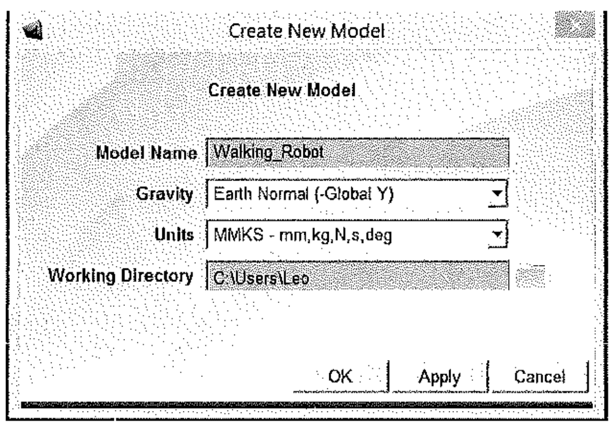


Figure 1: Creating a new model

B. Ground Surface

The next step is to create a surface for the robot to walk on. This surface can be modeled as a box that is fixed in place and spans enough distance for the robot to interact with. This box will have a length of 1500 mm, height of 50 mm, and a depth of 1500 mm, as shown in Figure 2. It will be placed on the far-left side of the horizontal X-axis. Figure 3 shows the exact coordinates and orientation of its marker to help users place the box in the same location. For example, the values for the first marker's location can be interpreted as: -750 mm in the X-axis, -50 mm in the Y-axis, and -500 mm in the Z-axis. The "Orientation" values are read in the same way, with degrees instead of centimeters.

After this, select the "Connectors" tab and choose the lock icon to fix the body in place. Make sure to change the first option to "1 Location – Bodies impl." and select the body's central axis. The result should be similar to Figure 4. This creates a surface plane for the robot's two legs to walk on that is fixed in space.

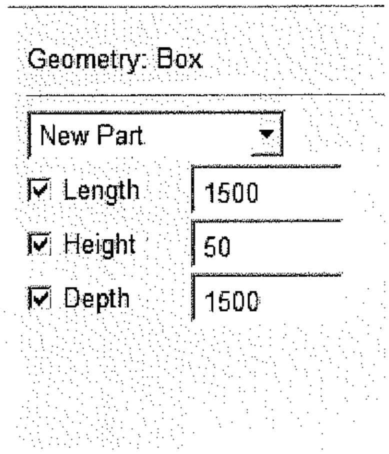


Figure 2: Box dimensions

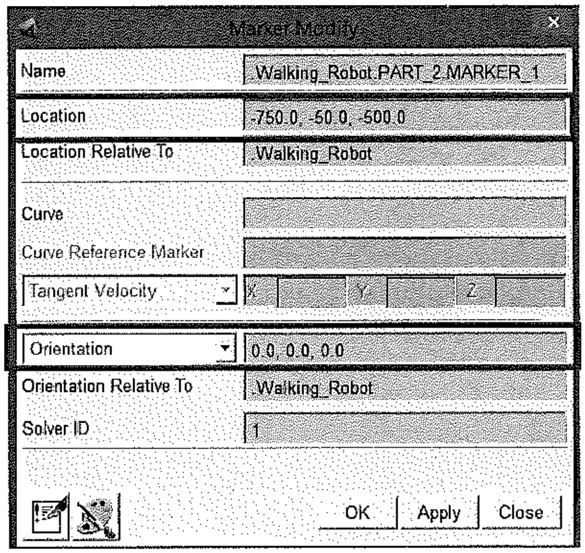


Figure 3: Marker location values

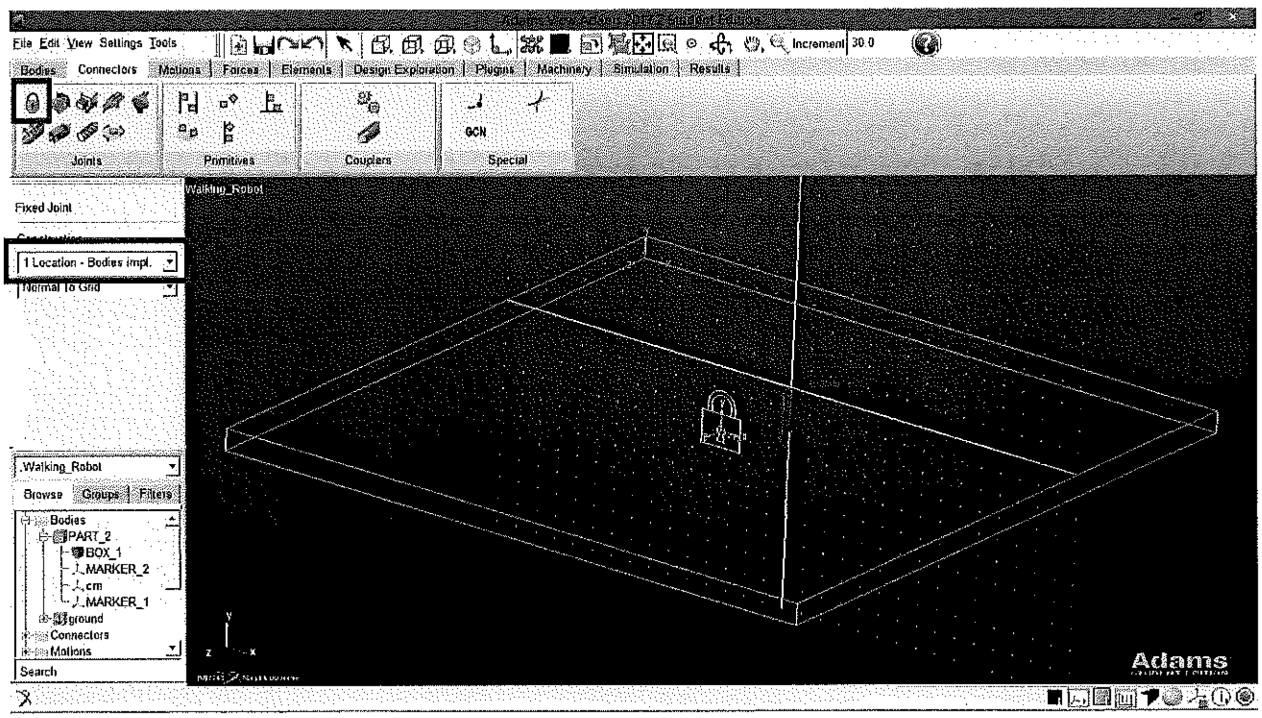


Figure 4: Ground surface result

C. Legs

The next step involves creating the legs of the robot. Each of the legs is made from four boxes and one cylinder. They are separated into two bodies to allow them to properly interact with each other. These legs are designed to keep the robot upright and balanced while allowing them to cross over each other without touching. The exact dimensions, locations, and orientations of both the boxes and markers are shown in the next few pages to provide help with the modeling process.

Refer to Figure 2 and Figure 3 to determine where to enter the values given in the tables. Note that the both legs have the same dimensions, but the left leg is located 100 mm away from the right leg in the Z-axis and is mirrored about the Y-Z plane.

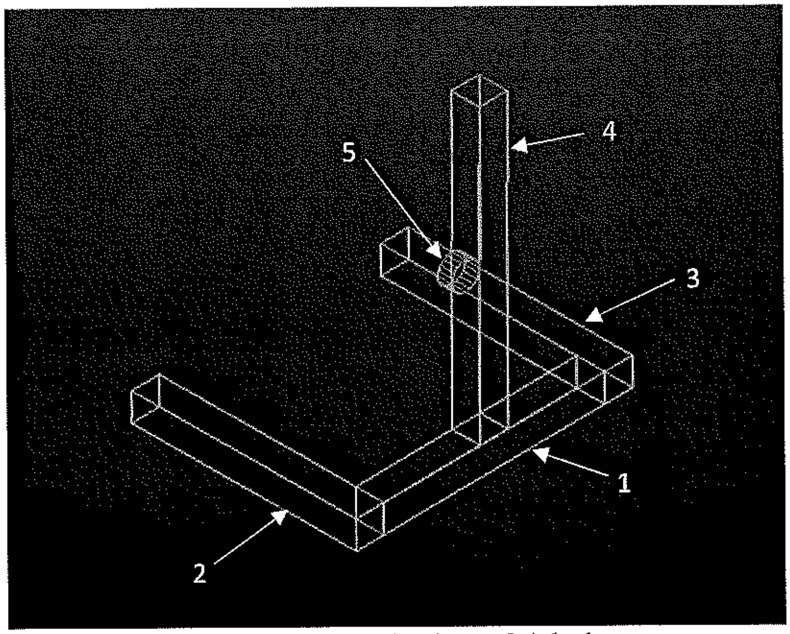


Figure 5: Isometric view of right leg

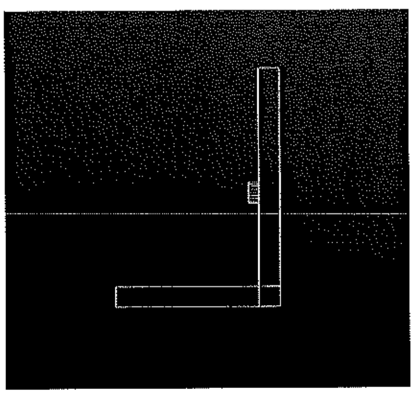


Figure 6: Front view of right leg

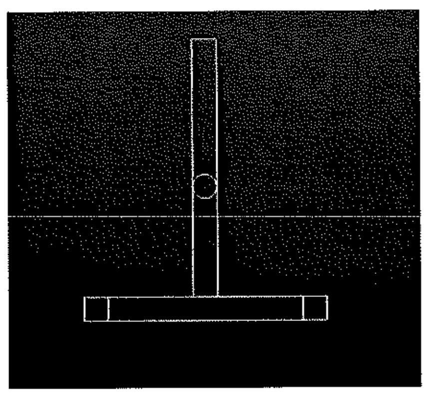


Figure 7: Side view of right leg

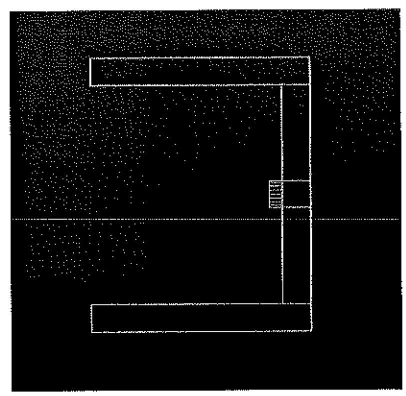


Figure 8: Top view of right leg

Table 1: Right Leg Part Dimensions

Part Number	Length (mm)	Height (mm)	Depth (mm)	Radius (mm)
1	50	50	400	N/A
2	400	50	50	N/A
3	400	50	50	N/A
4	50	525	50	N/A
5	25	N/A	N/A	25

Table 2: Right Leg Marker Defintions

	Marker Location			Marker Orientation		
Part Number	X (mm)	Y (mm)	Z (mm)	X (degree)	Y (degree)	Z (degree)
1	200	0	-200	0	0	0
2	-150	0	200	0	0	0
3	-150	0	-250	0	0	0
4	200	50	-25	0	0	0
5	200	275	0	270	90	180

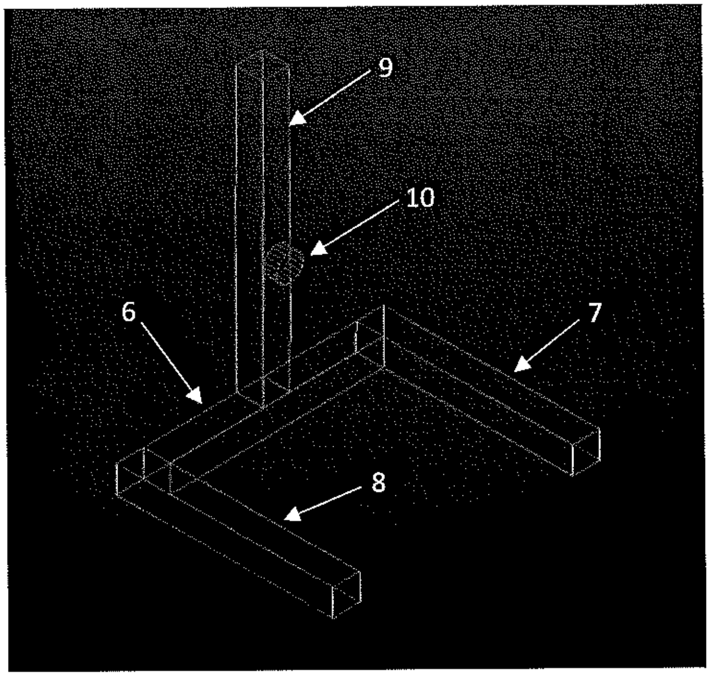


Figure 9: Isometric view of left leg

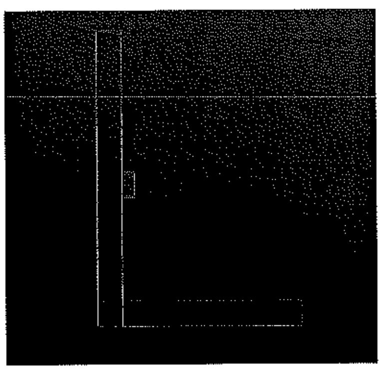


Figure 10: Front view of left leg

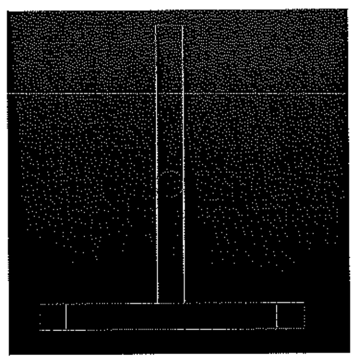


Figure 11: Side view of left leg

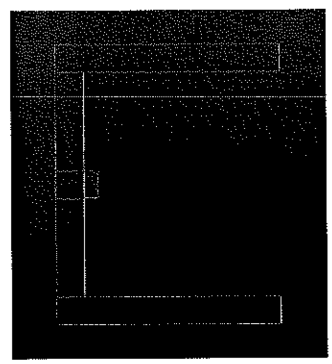


Figure 12: Top view of left leg

Table 3: Left Leg Part Dimensions

Part Number	Length (mm)	Height (mm)	Depth (mm)	Radius (mm)
6	50	50	400	N/A
7	400	50	50	N/A
8	400	50	50	N/A
9	50	525	50	N/A
10	25	N/A	N/A	25

Table 4: Left Leg Marker Defintions

	Marker Location			Marker Orientation		
Part Number	X (mm)	Y (mm)	Z (mm)	X (degree)	Y (degree)	Z (degree)
6	-250	0	-100	0	0	0
7	-250	0	-150	0	0	0
8	-250	0	300	0	0	0
9	-250	50	75	0	0	0
10	-200	275	100	90	90	0

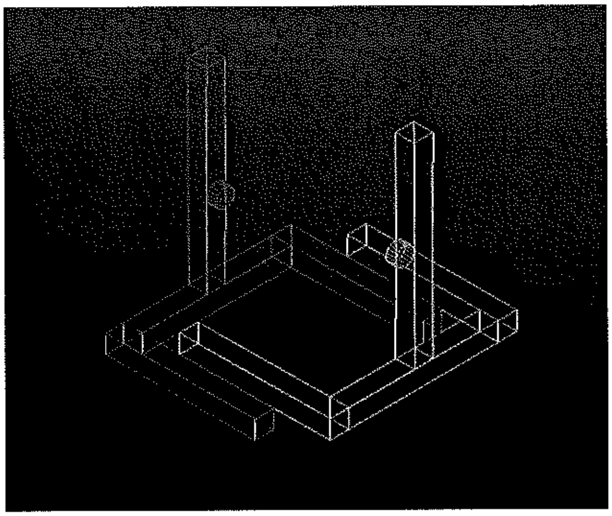


Figure 13: Isometric view of both legs

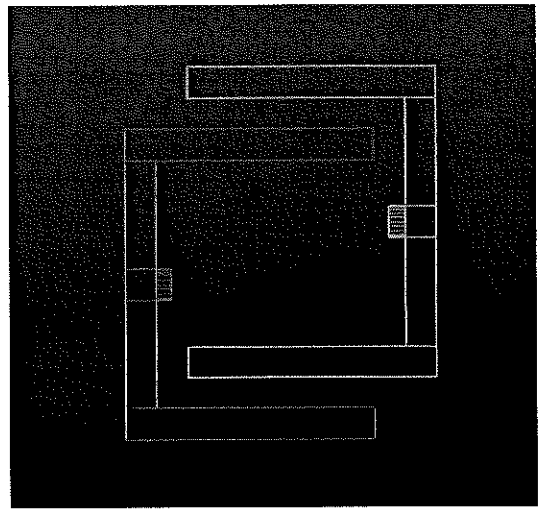


Figure 14: Top view of both legs

All the boxes and the cylinder of the right leg should be created under the same part and solid body; the same will applies to the left leg, but to a different part and solid body. There should be three parts that have been created so far: the ground surface, the right leg, and the left leg.

D. Flywheels

After creating the two legs, the next step is to create two flywheels that will connect the two parts together to allow the walking motion to occur. These can be modeled as two cylinders that are connected to the two legs. Both flywheels will be new separate parts, and will have the same dimensions: a radius of 75 mm and a length of 25 mm. Their orientation values are shown below.

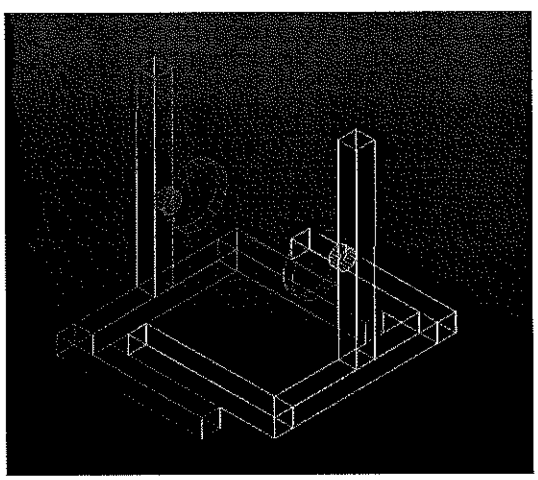


Figure 15: Isometric view of flywheels attached

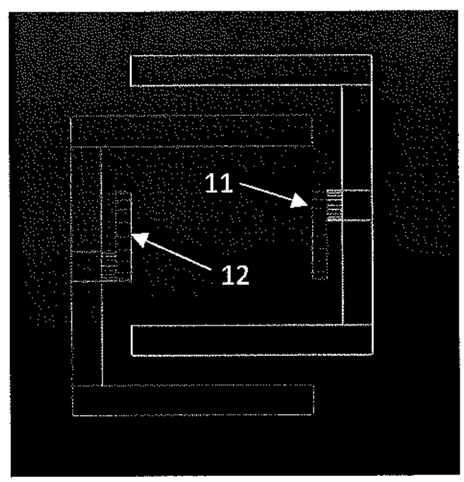


Figure 16: Top view of flywheels attached

Table 5: Flywheel Marker Locations

	Marker Location			Marker Orientation		
Part Number	X (mm)	Y (mm)	Z (mm)	X (degree)	Y (degree)	Z (degree)
11	150	275	50	90	90	0
12	-175	275	50	90	90	0

E. Axle

The next step is to create the axle that will connect the two flywheels and produce the walking motion of this robot. This axle can be modeled as a cylinder that attaches to both centers of the aligned flywheels. This is a new separate part and will be fully defined in the later chapters of this report. In this model, the axle has a radius of 37.5 mm and a length of 300 mm. It's marker locations are: -150 mm in the X-axis, 275 mm in the Y-axis, and 50 mm in the Z-axis. It's marker orientations are: 90 degrees in the X-axis, 90 degrees in the Y-axis, and 0 degrees in the Z-axis.

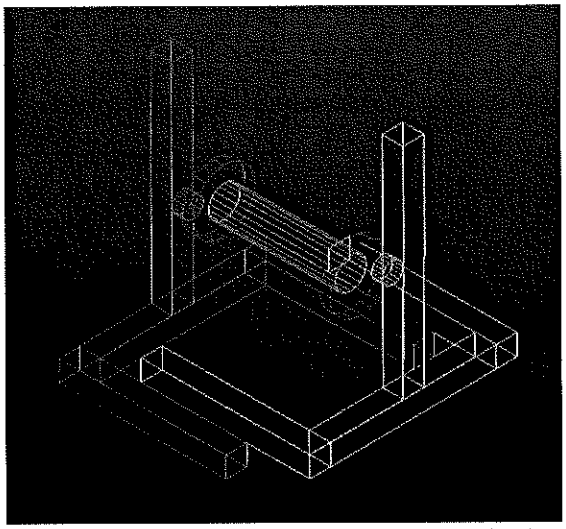


Figure 17: Isometric view of axle attached

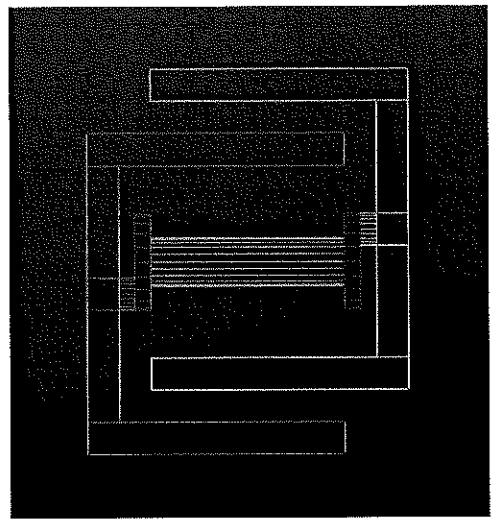


Figure 18: Top view of axle attached

F. Support Joints

Though it may seem that the model is completed, there are still a few components that need to be included for the robot to function properly. If the model is simulated as it is now, with the correct joints and forces, the legs will rotate as shown in Figure 19 below. This can be problematic as the legs can run into each other and stop the robot from operating properly. To prevent the leg rotation and only allow movement in the Y-axis and Z-axis, translational support joints must be added to the top of the model.

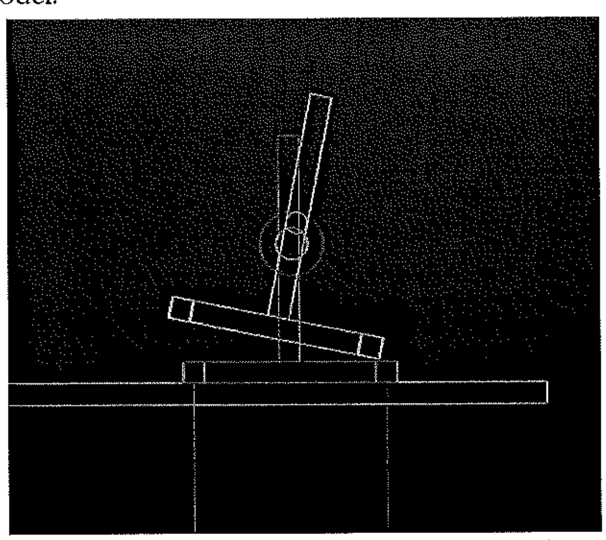


Figure 19: Leg rotation without support joints

These translational joints can be easily modeled as four boxes. Each of these boxes will be a new separate part, and will be attached to the tops of both legs and each other as well. They will only translate in either the Z-axis or the Y-axis. The dimensions and marker locations of these boxes are shown in the tables below.

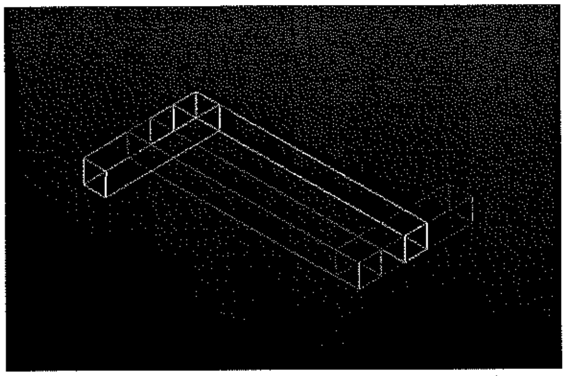


Figure 20: Isometric view of support joints

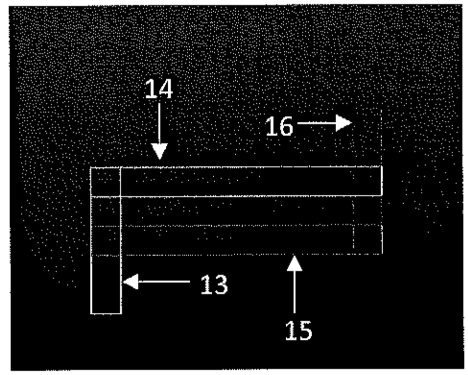


Figure 21: Top view of support joints

Table 6: Support Joints Part Dimensions

Part Number	Length (mm)	Height (mm)	Depth (mm)
13	50	50	250
14	500	50	50
15	500	50	50
16	50	50	250

Table 7: Support Joints Marker Defintions

	Marker Location			Marker Orientation		
Part Number	X (mm)	Y (mm)	Z (mm)	X (degree)	Y (degree)	Z (degree)
13	-250	425	-25	0	0	0
14	-250	425	-25	0	0	0
15	-250	425	75	0	0	0
16	200	425	-125	0	0	0

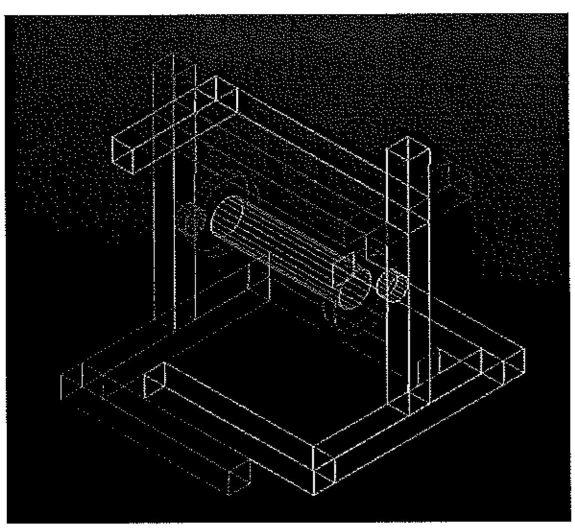


Figure 22: Isometric view of entire model

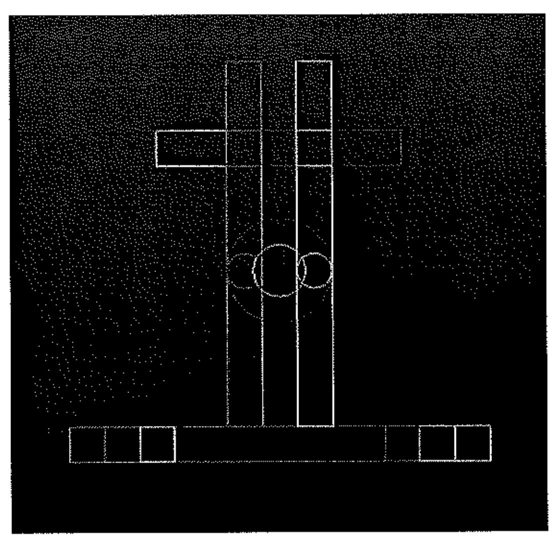


Figure 23: Side view of entire model

III. Joint Attachments and Forces

Now that all the parts of the robot have been modeled, the joints and forces must be properly attached so that the walking motion will occur properly. First, the contact forces from the legs of the robot to the ground surface must be added to the simulation. This is done by selecting the "Forces" tab at the top and choosing the contact force option from the "Special Forces" menu.

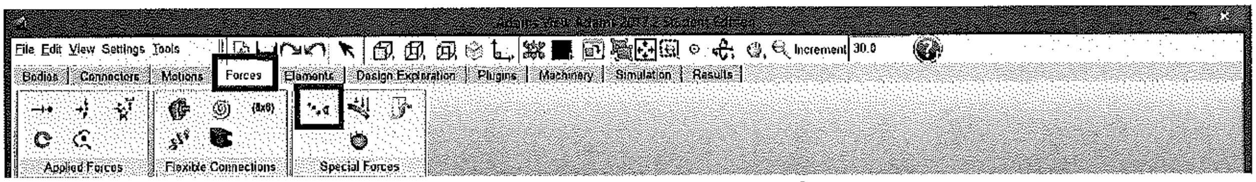


Figure 24: Selecting the contact force

Next, this menu below will be displayed. Right click the "I Solid(s)" section, navigate to appropriate choice, and the select a box from a leg that will be touching the ground surface. Then, repeat the same process in the "J Solid(s)" section, but select the ground surface instead. Also, make sure that the friction force is turned on, by selecting the "Coulomb" option from the choices in the "Friction Force" section. Without friction, the legs will slide against the ground surface and the robot will not be able to walk. Once these steps are completed, click "OK" at the bottom. This process must be repeated for all the boxes of the two legs that are in contact with the ground.

Another contact force to add is between the two legs of the robot. Though the legs will not touch in this simulation, it is added in precaution if they do. Repeat the same process as above, but select the other box from the other leg for the "J Solid(s)" instead of the ground surface.

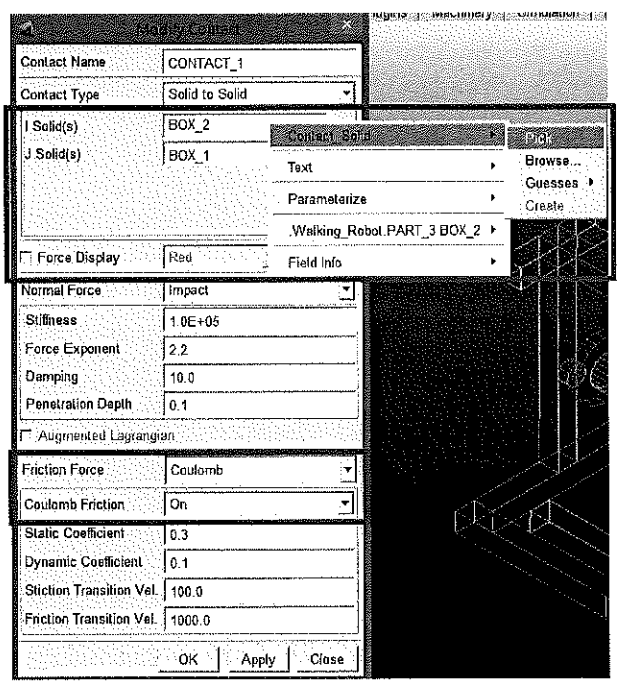


Figure 25: Contact Force menu

These contact forces are the only forces that will be needed for this simulation. The walking robot does not need additional forces to operate, and these contact forces are used to allow the robot to walk along the ground surface.

Next, the joints of the robots must be attached. This is the most critical part of the simulation; if these joints are not attached correctly, the simulation will not operate as planned. The joints may be difficult to attach because of other parts in the same vicinity, so consider hiding certain parts that obscure the attachment locations.

The first two joints must be attached between the cylinders of the legs to the flywheels. This is done by selecting the revolute joint in the "Connectors" tab in the "Joints" menu.

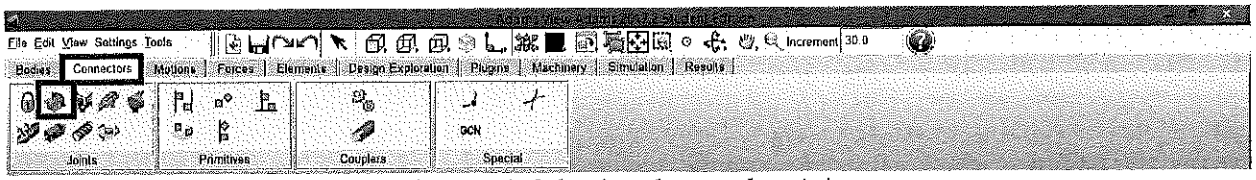


Figure 26: Selecting the revolute joint

First, select the leg that the revolute joint is being attached to. After that, select the flywheel that will be moving that leg. Next, choose the location of where the joint will be, which is in the center of the cylinder from the leg. Then, select that same location for the direction vector, which should in the direction of the positive X-axis, as shown in the figure below. The location of the joint and its direction vector are important, and if not done correctly, the joint will not rotate correctly. Repeat these steps for the other leg and flywheel as well.

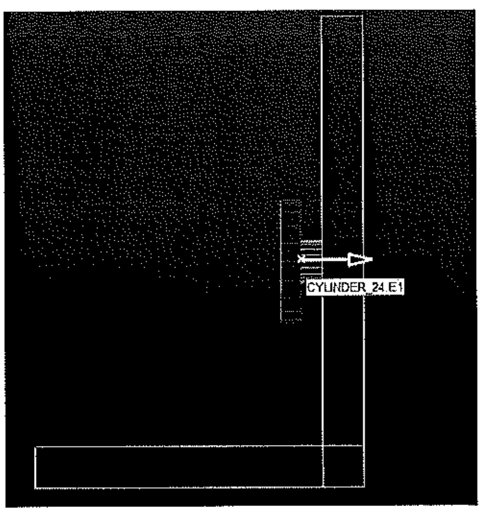


Figure 26: Joint location and direction of right leg

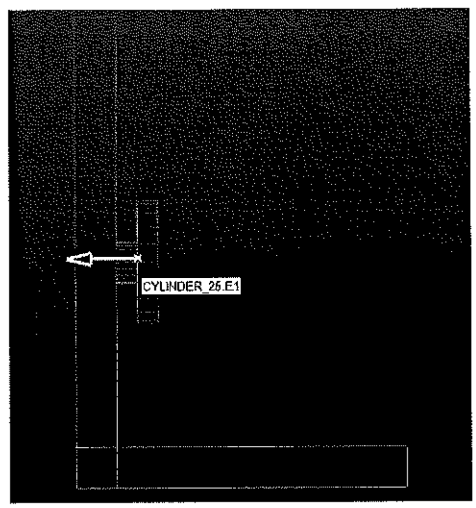


Figure 27: Joint location and direction of left leg

The next step is to create revolute joints between the flywheels and the axle that connects them together. This is done by the same steps as the previous revolute joints, but the location will be in the center of the axle and flywheel instead. An example of what the joint location and direction should be is shown in the figures below.

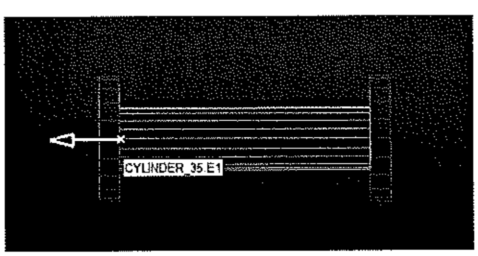


Figure 28: Joint of the axle (left)

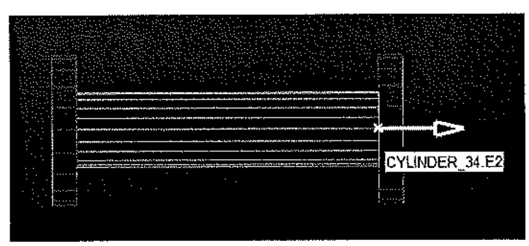


Figure 29: Joint of the axle (right)

These joints must be coupled together to properly transmit the velocity of the axle to the flywheels to the legs. If this step is not performed, the axle and flywheels will rotate independently of each other and will not produce the walking motion. This is done by selecting the coupler joint in the "Couplers" menu in the same tab.

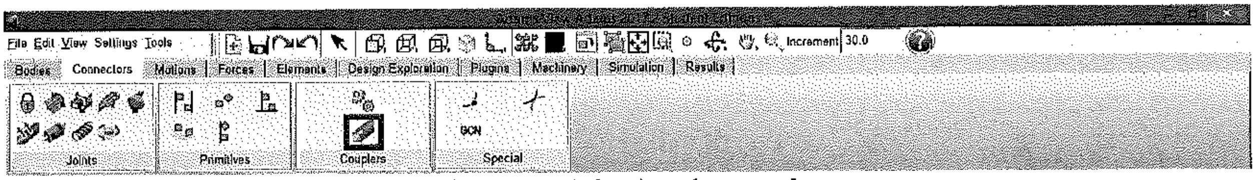
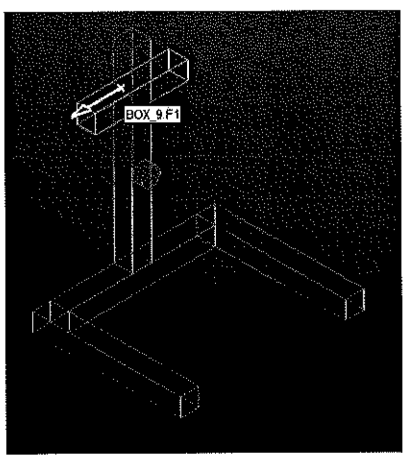


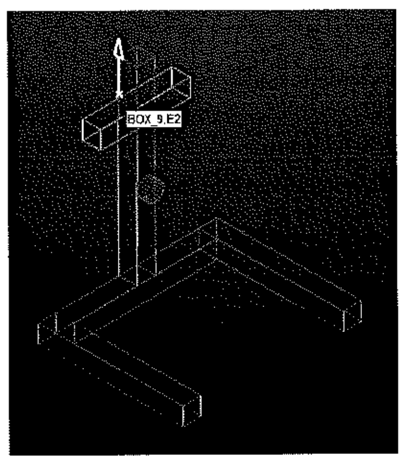
Figure 30: Selecting the coupler

First, select the revolute joint between the left leg and the left flywheel. Then, select the joint between the left flywheel and the axle. This will couple them together and allow them to rotate with the same velocity. Repeat this step with the two other joints on the right side.

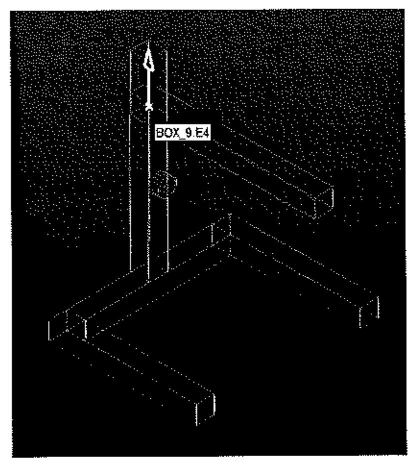
The next step is to apply translational joints to the support joints at the top of the robot. This is done in the same process as the revolute joints, however, there will be multiple joints for each part. These joint assignments will be complicated, so follow the joint assignment process as shown in the steps below. They each show the two parts that are being joined and the direction of the translation.



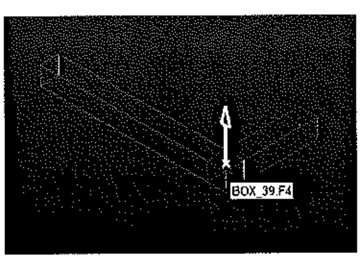
Step 1: Assign joint in Z-axis



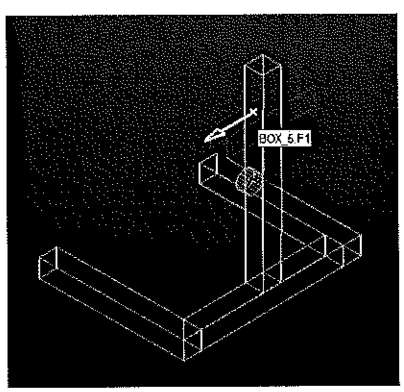
Step 2: Assign joint in Y-axis



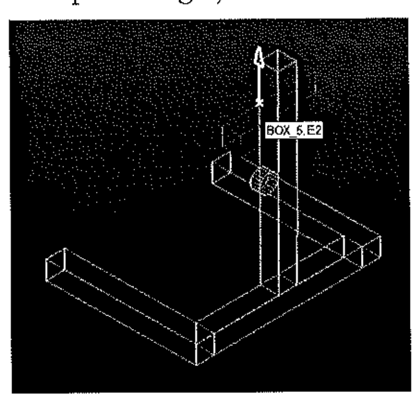
Step 3: Assign joint in Y-axis



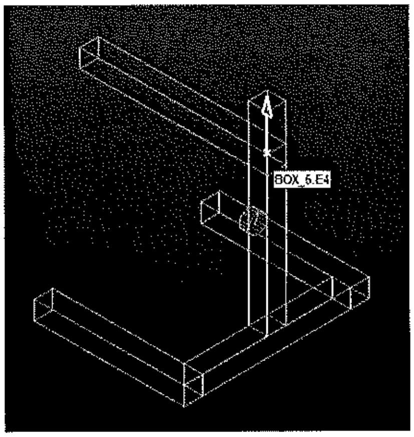
Step 4: Assign joint in Y-axis



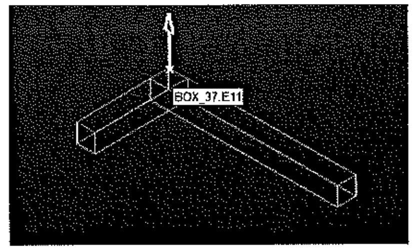
Step 5: Assign joint in Z-axis



Step 6: Assign joint in Y-axis



Step 7: Assign joint in Y-axis



Step 8: Assign joint in Y-axis

Once finished with these joint assignments, the final step is to add a revolute joint motion to one of the couplers created in the previous steps. This will provide the velocity to allow the robot to walk along the ground surface. This revolute joint motion can be found under the "Motions" tab and in the "Joint Motion" menu.

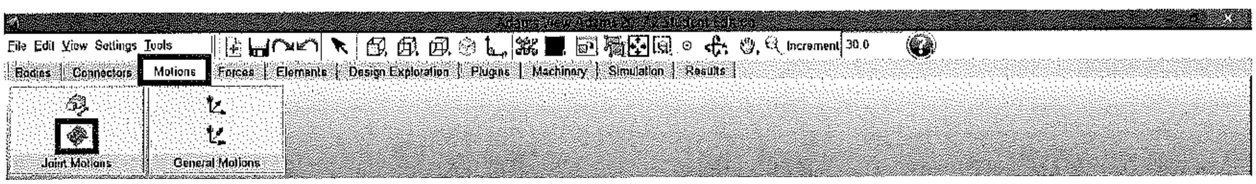


Figure 39: Selecting the revolute joint motion

Apply the joint motion to either revolute joint between the axle and the flywheel. Once selected, modify the newly created joint motion and increase its speed by changing the "Function (time)" value as shown in the figure below. Change its value to: 200.0d*time.

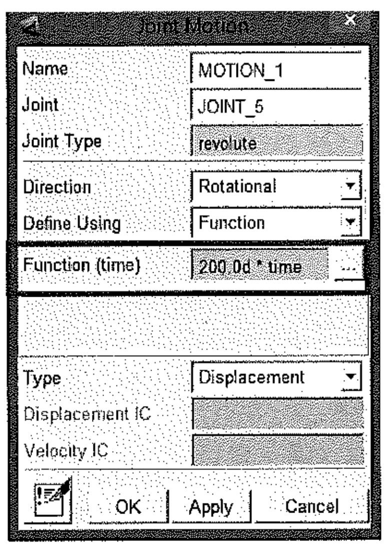


Figure 40: Joint Motion menu

IV. Simulation Results

After completing the robot modeling, joint attachments, and force and motion assignments, the simulation finally is able to run. Select the "Simulation" tab and click the gear icon in the "Simulate" menu.

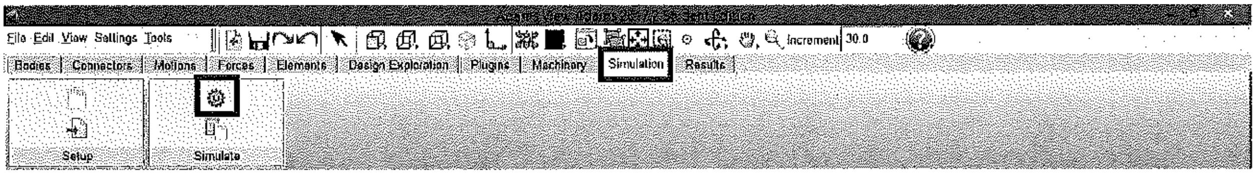


Figure 41: Running the simulation

The next menu will open on the screen. Change the end time to 10 seconds, and increase the number of steps to 1000. Finally, press the play button to run the simulation. The robot will proceed to walk along the ground surface up until the edge where it falls off. A video file of the simulation will be provided to show the motion of the walking robot, as well as the project file for ADAMS to analyze how the robot was modeled.

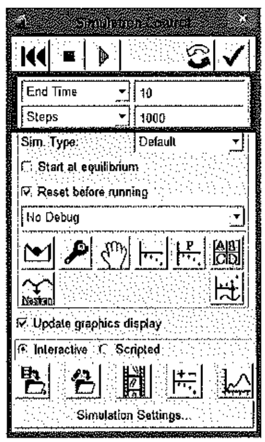


Figure 42: Simulation Control menu

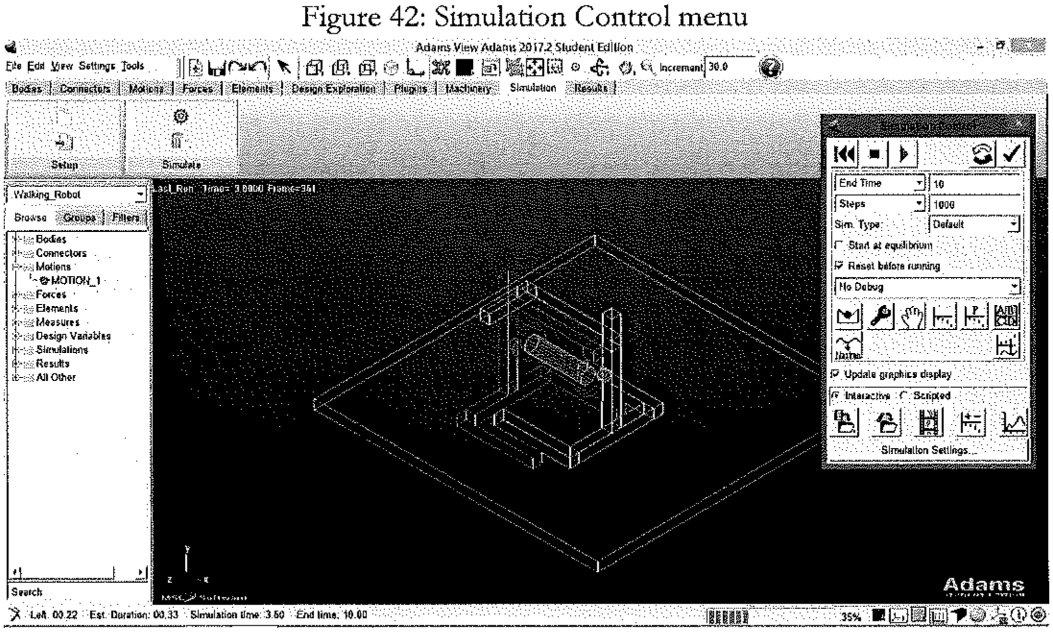


Figure 43: Screen capture of simulation results

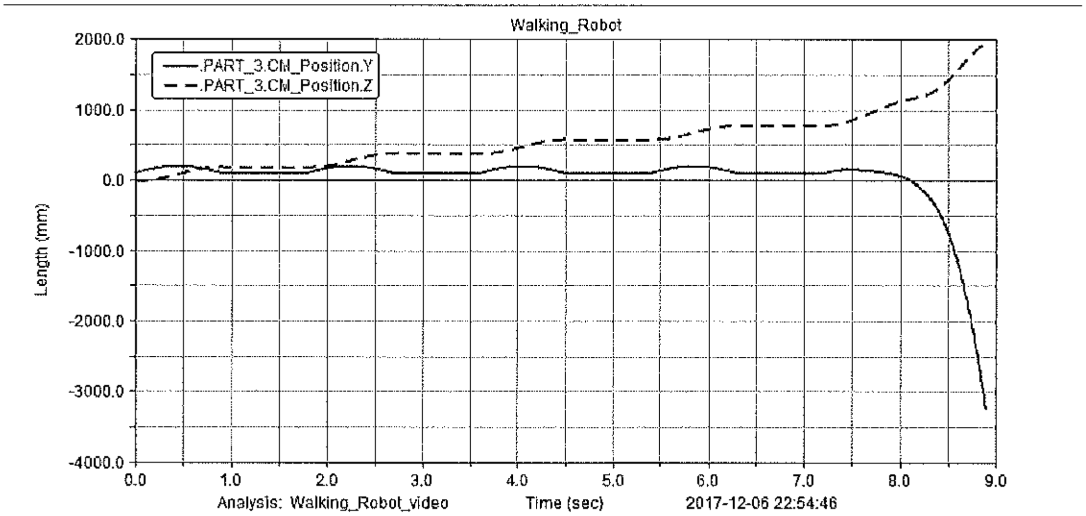


Figure 44: Positions of the robot right leg over time

A more careful analysis of the robot's position is shown on the plot above. The red line indicates the location of robot's right leg in the Y-axis over the simulation time. The blue line shows the location of the same leg in the Z-axis. This plot shows that the robot is steadily moving across the surface in the Z-axis. This was confirmed with the animation of the robot walking along the surface. The rise and fall of the red line shows that the robot leg is moving up and down the Y-axis as it is walking along the surface. At the end, the results show the robot falling off the surface, as indicated by the drop of the red line.

V. Conclusion

The simulation results showed that the robot could walk along the ground surface and remain upright until it fell off at the end. The software allowed the user to assign the correct joint locations, forces, and motion to allow the robot to walk. Also, the physics of the ADAMS software allows for careful analysis and simulation of robotic systems, which is useful for many engineering applications. In conclusion, this walking robot demonstrates the usefulness of this modeling software, as well as the showing the application of knowledge of robotics.