Section 1 - Group 7

Mechanics of Kicking a Soccer Ball

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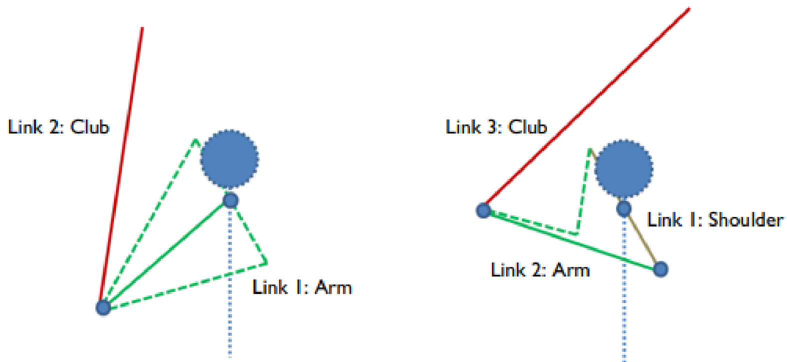
Setup

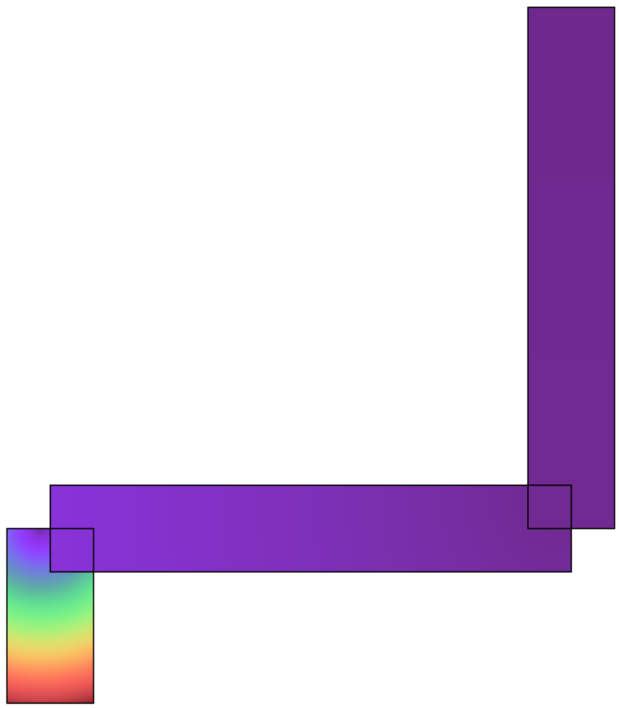
The main goal of this project is to analyze the motion of a person kicking a soccer ball. For the setup, the simulation of the swinging motion when hitting a golf ball is referenced. The arm connected to the club seems similar to the motion of the leg kicking. The picture shows the motion of the arm and club swinging while hitting a golf ball.



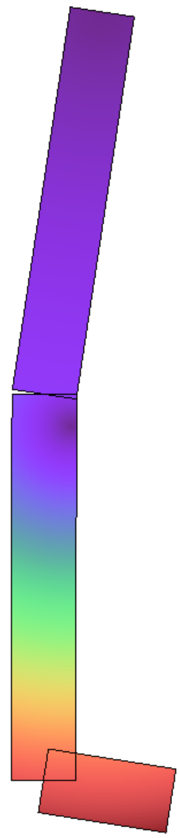
This concept is similar to the way it moves from thigh to knee, lower leg to ankle and combined with foot.

Kicking Mechanics

The golf Comsol file was used as the base of this project. Model and parameters were later recreated. Two longer rectangles were created to simulate thigh and lower leg and a shorter rectangle was used to simulate the foot. The torque applied by the thigh, lower leg and the foot is assumed. The motion of swinging the golf ball has two phases, while in this project, only one phase is needed, which is that the leg swings from a 90 degree angle to around 180 degrees towards the front to kick the soccer ball. At first the two longer rectangles are set 90 degrees to each other and the foot is 90 degrees to the lower leg. As the legging is kicking, the knee part where two longer rectangles are attached turn to 180 degrees. The top of the thigh is always fixed, the thigh rotates a little but not as much as the lower leg.



Beginning of the motion



End of the motion

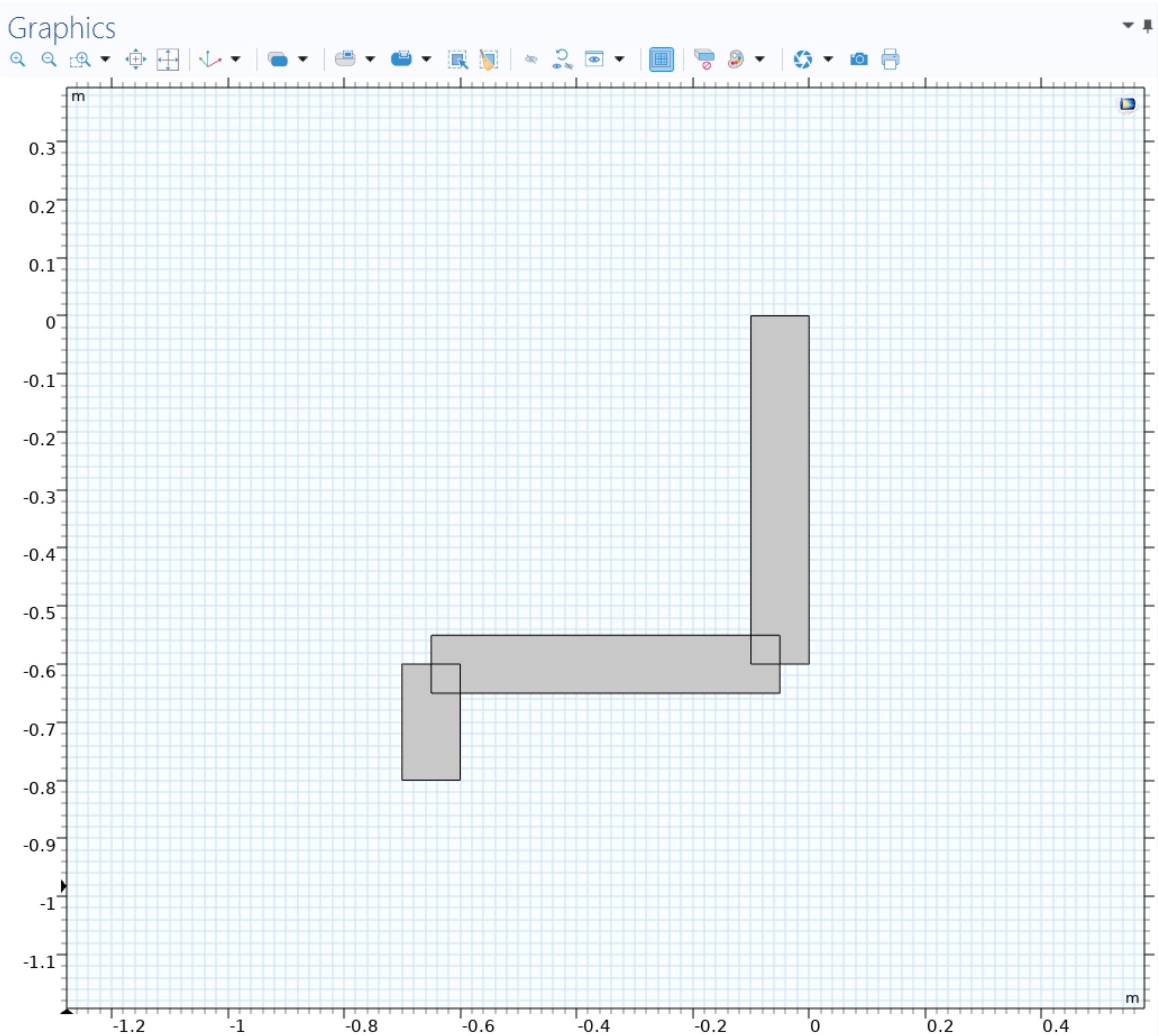
See there is a tiny rotation at the ankle part at the end of the motion, which simulates when the foot kicks the ball, the ball “pushes” the foot back therefore the ankle would rotate a little bit. Also, by analyzing soccer players’ videos of kicking a ball, because the torque is huge, the lower leg will extend at the knee part which is a little bit larger than the actual 180 degrees.

The parameters shown below are considered as the average human body.

Name	Expression	Value	Description
Ig	0.01367[kg*m^2]	0.01367 kg·m²	Moment of inertia of grip
Ic	0.02571[kg*m^2]	0.02571 kg·m²	Moment of inertia of club
tw	0.1[s]	0.1 s	Wrist torque switch time
xb	0.15[m]	0.15 m	Ball position, x-coordinate
Mc	0.2924[kg]	0.2924 kg	Mass of club
Ia	0.354[kg*m^2]	0.354 kg·m²	Moment of inertia of arm
Ish	0.8[kg*m^2]	0.8 kg·m²	Moment of inertia of shoulder
Mg	1.8994[kg]	1.8994 kg	Mass of grip
lambda	100[1/s]	100 1/s	Switch rate parameter
kw	1000[N*m/rad]	1000 N·m/rad	Wrist stop stiffness
ks	2000[N*m/rad]	2000 N·m/rad	Shaft joint stiffness
Ta_max	209.34[N*m]	209.34 N·m	Maximum arm torque
Tsh_max	272.64[N*m]	272.64 N·m	Maximum shoulder torque
Ta_rate	3326[N*m/s]	3326 N·m/s	Rate of change of arm torque
Tw_max	34.67[N*m]	34.67 N·m	Maximum wrist torque
ca	5[N*m*s/rad]	5 N·m·s/rad	Arm stop damping coefficient
cw	5[N*m*s/rad]	5 N·m·s/rad	Wrist stop damping coefficient
cs	5[N*m*s/rad]	5 N·m·s/rad	Shaft joint damping coefficient
ka	5000[N*m/rad]	5000 N·m/rad	Arm stop stiffness
Ma	8.644[kg]	8.644 kg	Mass of arm

Physics coupled

In our project we need to analyze the motion of kicking soccer. To model the motion of kicking a soccer ball, we can use a physics engine to simulate the motion of the various parts of the leg. This typically involves dividing the leg into separate segments, such as the foot, calf, thigh, and knee, and representing each segment as a collection of rigid bodies connected by joints.



To simulate the motion of the leg, we will need to specify the physical properties of each body, such as its mass, shape, and material properties. We will also need to specify the properties of the joints that connect the bodies, such as the range of motion, stiffness, and damping.

Once we have specified the physical properties of the bodies and joints, we can use a physics engine to simulate the motion of the leg as it swings through the kicking motion. The physics engine will use the laws of physics, such as Newton's laws of motion and the laws of conservation of energy and momentum, to calculate the forces and torques acting on each body and the resulting acceleration, velocity, and position of each body over time.

We can also include additional physics phenomena in wer simulation, such as friction, air resistance, and contact forces between the leg and the soccer ball. This can help to make the simulation more realistic and accurate. However, in our project we won’t consider these elements.

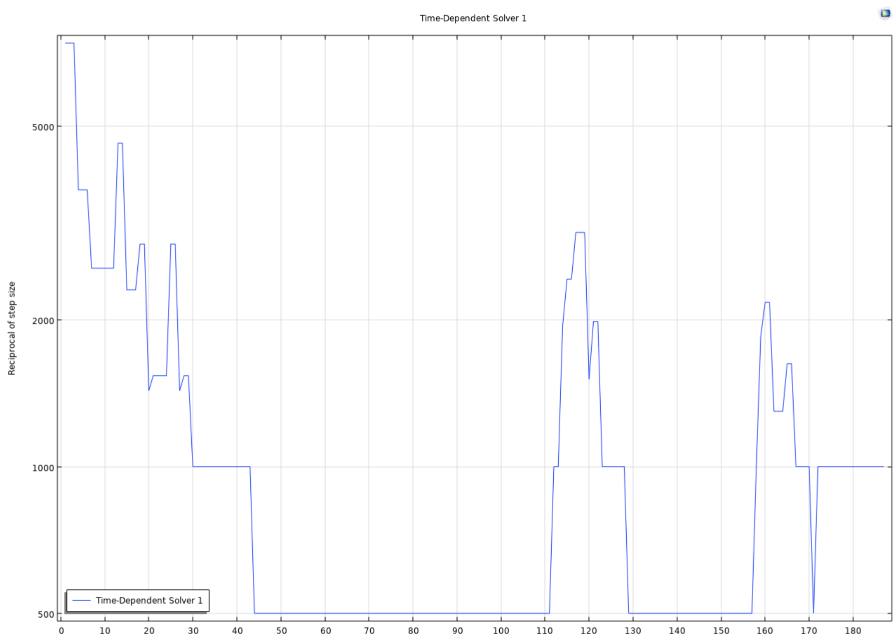
Overall, coupling different physics in a simulation of a kicking soccer ball involves specifying the physical properties of the bodies and joints, and using a physics engine to calculate the motion of the leg over time based on the laws of physics.

Mesh Convergence

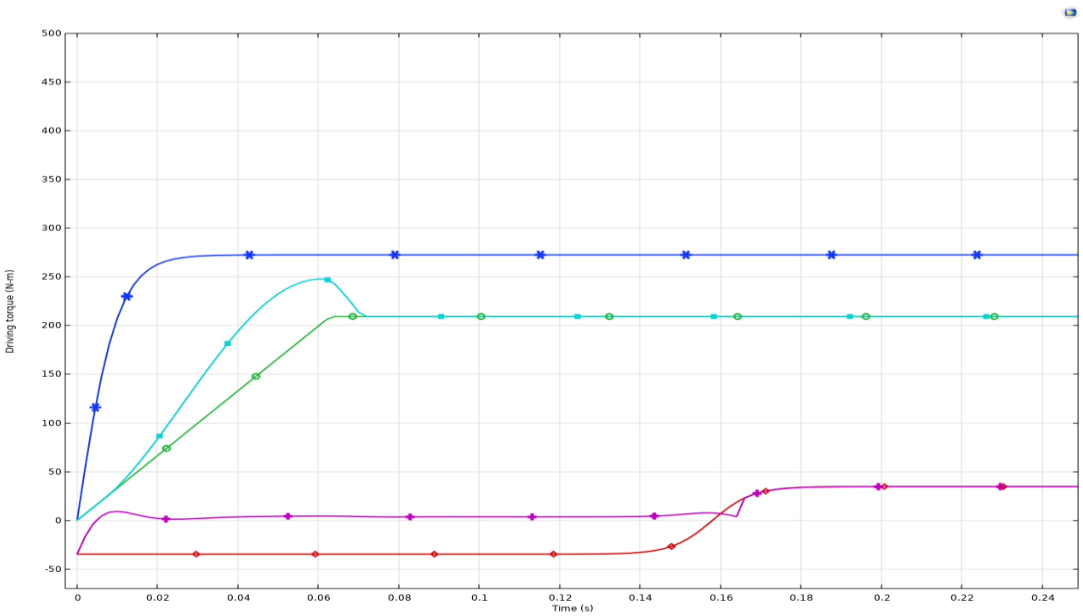
One of the key questions that the group had come up with was what mesh size was best suited for the simulation being performed. In our case, the geometry was very simple so it was hard to tell what mesh sizes, if any, were making a difference to the result of the project. In order to come up with this answer, it was apparent that the group needed to compare the data of different plots at different mesh sizes. First off was the mesh convergence plots.

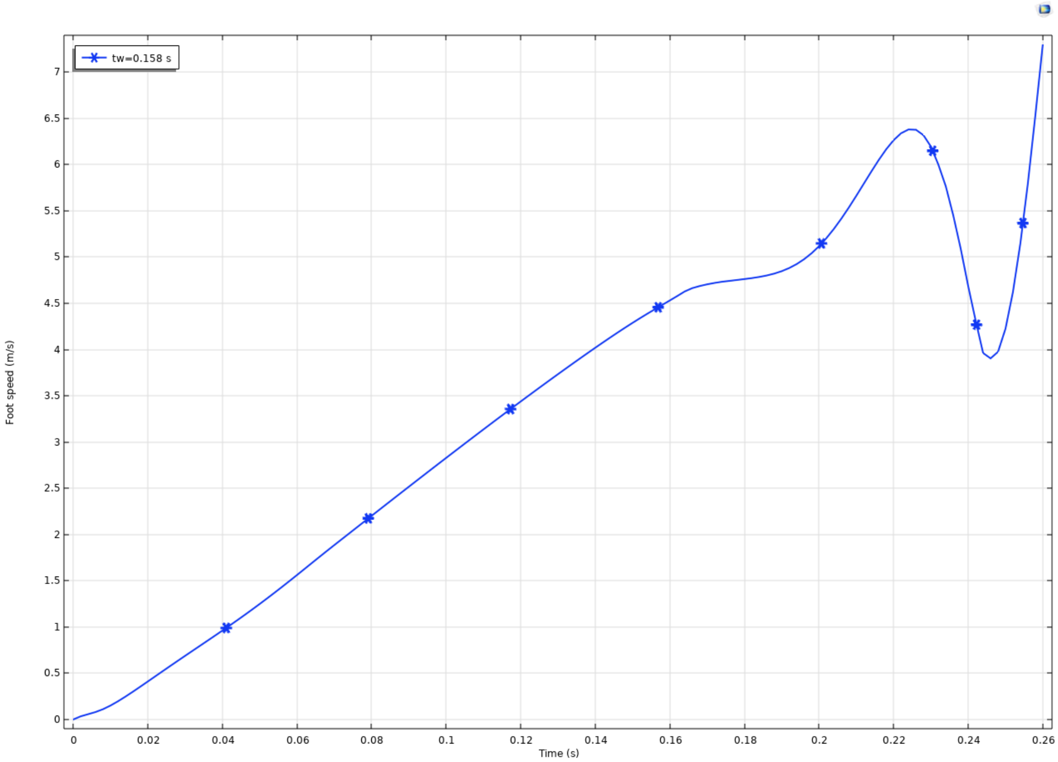

Time-Dependent Solver 1
Reciprocal of step size
5000
2000
1000
500
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
Time step
Time-Dependent Solver 1

●


Time-Dependent Solver 1
Reciprocal of step size
5000
2000
1000
500
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
Time step
Time-Dependent Solver 1

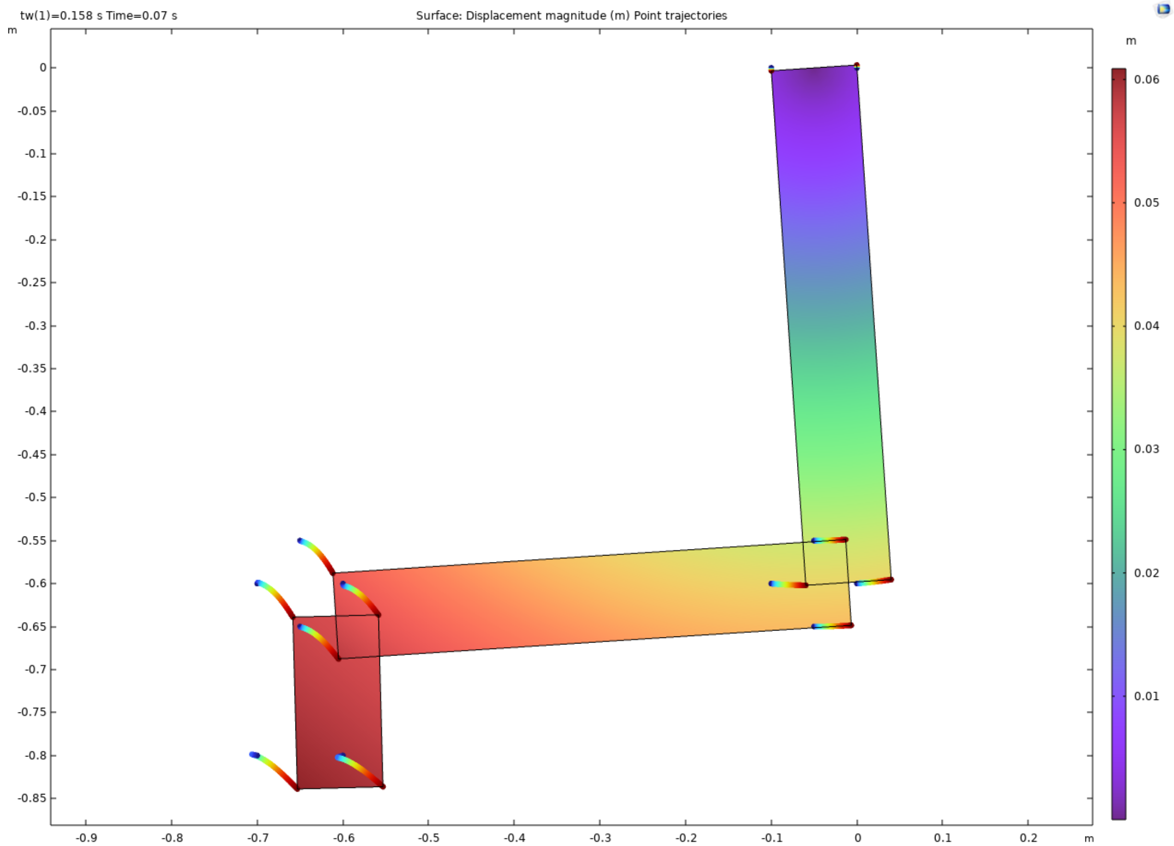
Despite looking the same, pictured above is actually the convergence plots at three different mesh sizes; fine, finer and extra fine. The simulation was also run on coarse and extra coarse in order to compare and yet we found the same results as pictured above. The group came to a conclusion that due to the simplicity of the geometry of our model as well as the lack of interaction between entities, any mesh size that was chosen was adequate for mesh convergence. The group also tested, and found similar results for, the foot speed plot and torque graphs shown below.



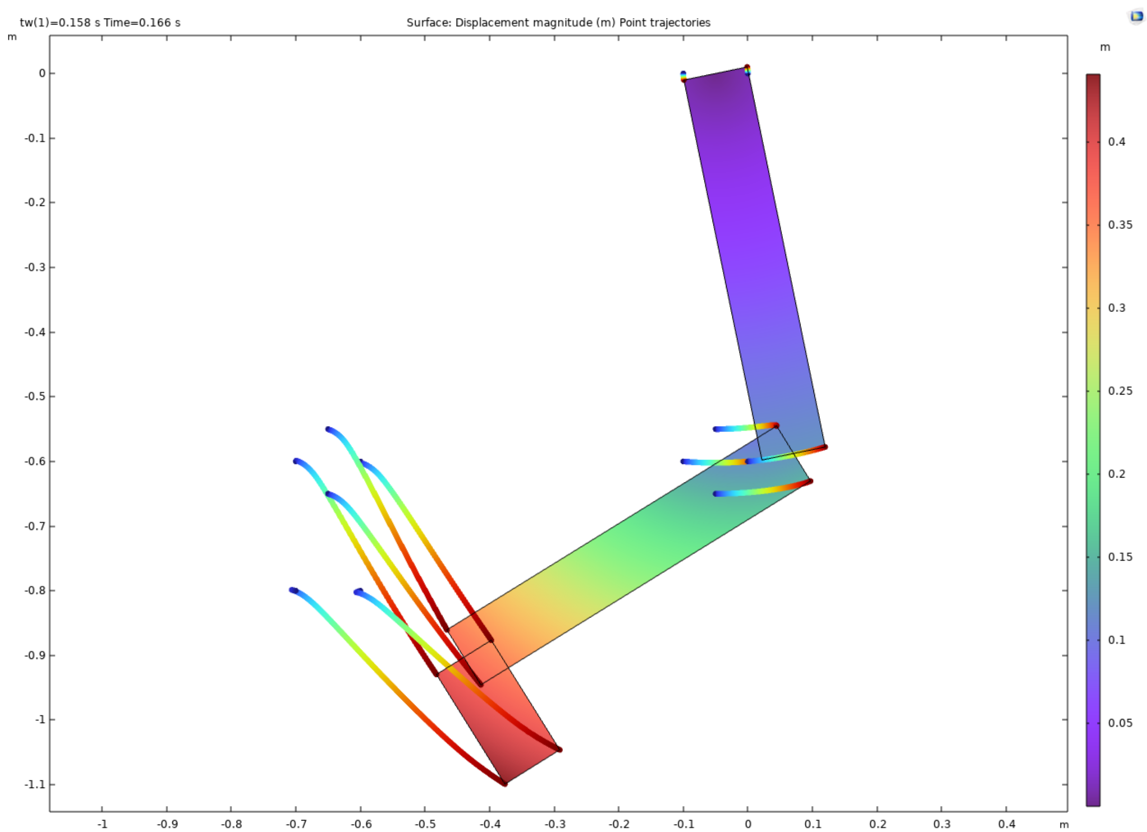


Both the foot speed and torque graphs were tested on different mesh sizes as well and found the same result as the convergence plot.

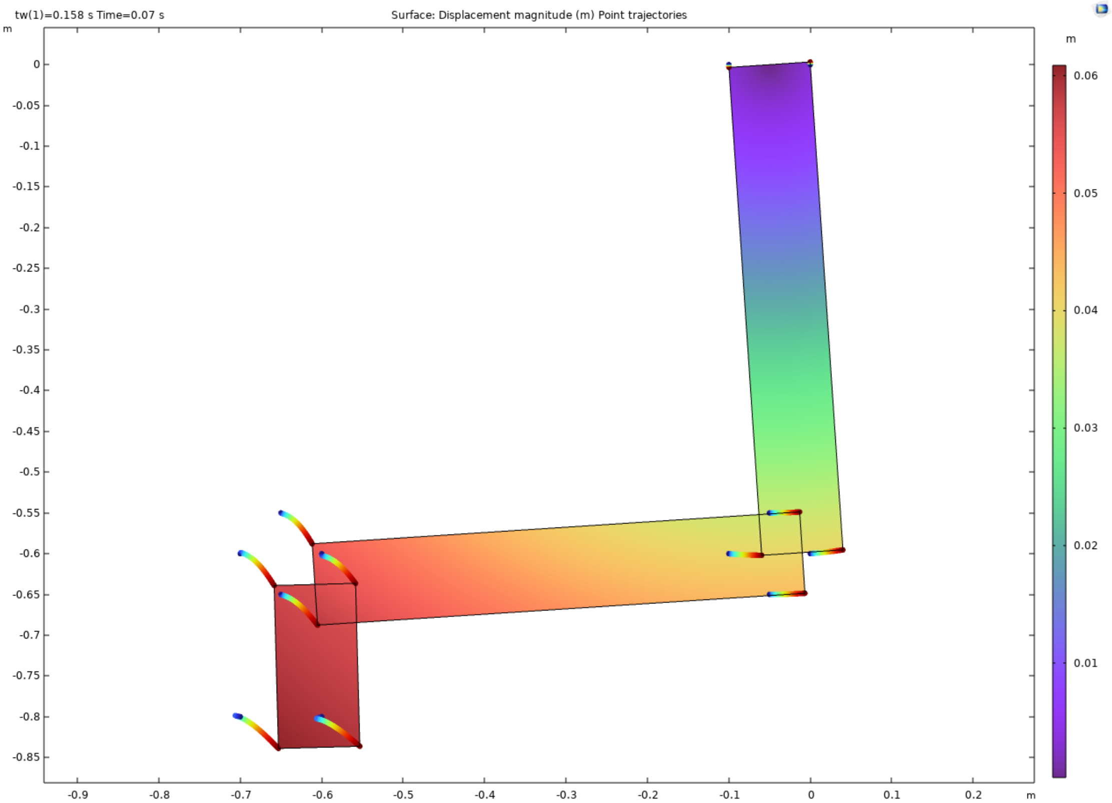
The group found out that the data seemed to be the same no matter what the mesh size was so we decided to test if there was any visual difference on the displacement graph.

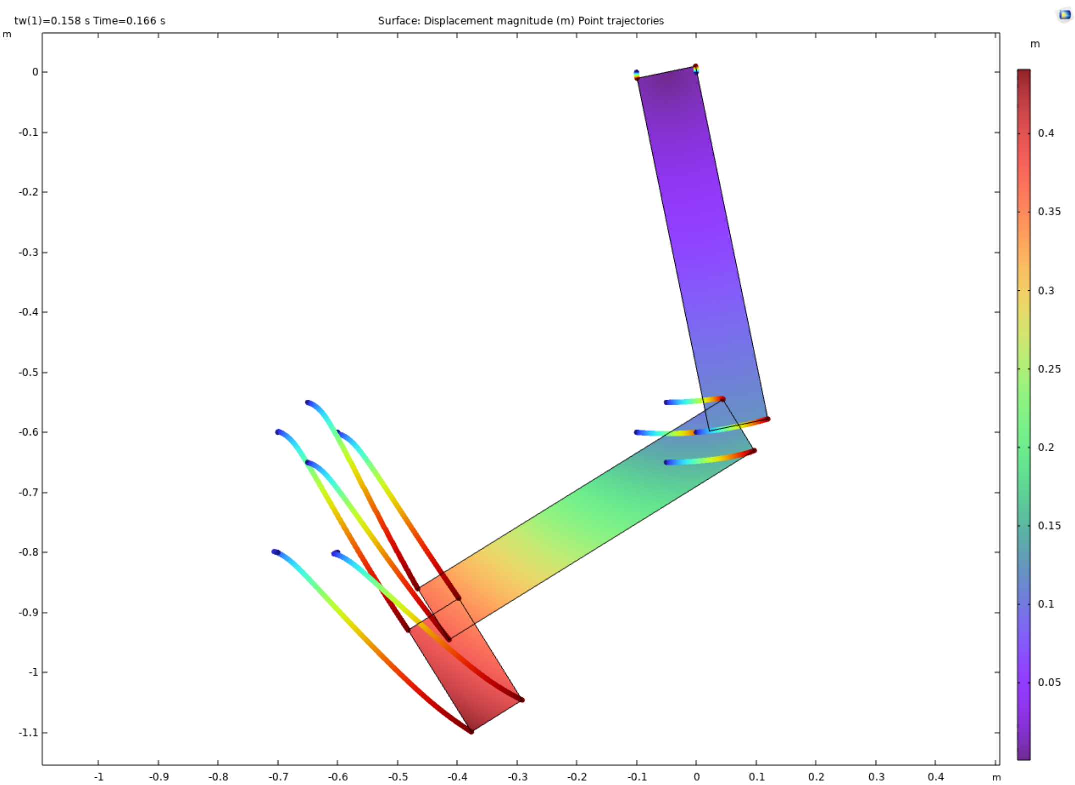


tw(1)=0.158 s Time=0.07 s
Surface: Displacement magnitude (m) Point trajectories
m
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
-0.35
-0.4
-0.45
-0.5
-0.55
-0.6
-0.65
-0.7
-0.75
-0.8
-0.85
-0.9
-0.8
-0.7
-0.6
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
m
0.06
0.05
0.04
0.03
0.02
0.01



tw(1)=0.158 s Time=0.166 s
Surface: Displacement magnitude (m) Point trajectories
m
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1
-1.1
-1
-0.9
-0.8
-0.7
-0.6
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
m
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05





The tests were once again run on different mesh sizes. This time the top row of the displacement graphs are extremely fine mesh and the bottom row in normal mesh size. This drastic difference between mesh sizes was chosen in order to increase the chance that we would notice a difference in results. As it turns out once again there was no difference. This led the group to come to the conclusion that the mesh size did not have a significant result on the outcome of the data produced so a fine mesh size was chosen as a default.

Insight

The insight that the group found was that no matter the mesh size used the results would be the same due to the simplicity of the design. This allowed us to understand the stresses that this figure underwent even though the mesh size did not provide any significant results. We can see from the images above that at different points of the leg kicking the stress distribution changes at different points in the joints. We can assume that at different speeds the stress in the figure would vary throughout the system. For example at low speeds we can assume that there would be less stress on the figure and at high speeds the stress would increase on the figure. We can also see that at different velocities the joints undergo stress at different angles causing an increase in speed at those varying angles. We also understood from the simulations the way the foot works in terms of stress and strain as it goes into the motion of kicking. We understood that at a 90 degree stationary angle the foot has low stress and minimum velocity, but as the foot goes into the kicking motion the velocity increases as well as the stress on all the components of the foot. For our problem we were measuring the behavior of the joints when stress and velocity are added onto the foot.

Some more insight the simulation revealed was while the foot is coming down for a kick it experiences a drag force pulling acting in the opposite direction as the foot is heading in a downward motion. The drag force can be found because of the frictional force caused by the air acting on the foot but the force is very minimal and has little effect on the system. As the foot is moving in a downward motion the angles of foot change causing the stress distribution and the velocity to increase before impact with the soccer ball. The leg also experiences a similar reaction from the knee joint to the ankle, which can be seen as an increase in velocity while the leg is moving in a downward motion while also the stress distribution changes from the knee to the ankle joints. This allowed us to understand the change in stress distribution and the change in velocities at different angles as the leg goes into the kicking motion. The simulation also showed us the stress distribution and the velocities on each component and how the these components were affected as the leg moved in a downward direction.

What to do next

If the time were available, the next step would be to add geometry as well as another hinge joint for the upper body of the simulation. In the beginning the plan was to add the upper body into the simulation from the start, but we got so caught up in problems with getting the simulation to run in the first place that it was not possible to add in time. The physics of the upper body may change the way that our outcomes look when performing opposing torque components when in motion. These results may be even more accurate to the real world mechanics of kicking a soccer ball and may be something that we look into adding during our free time over break.