The **Razor Clam** is a common name for a species of cold-blooded muscles or clams known for their ability to descend and ascend through sand with minimal energy. This is achieved with a strong muscle that is used to pull the body of the clam up or down using surrounding sand as an anchor point.

Parameter Identification

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Abstract

This report examines data from the various aspects of team fours current bio-inspired mechanism. These aspects include: the full system, actuator parameters, energy storage, system and link stiffness, as well as damping and friction coefficients. The data collected throughout this report will be used to further define and improve the robotic clam design that the team is currently developing.

1. TRACKING THE MOTION OF A JOINT

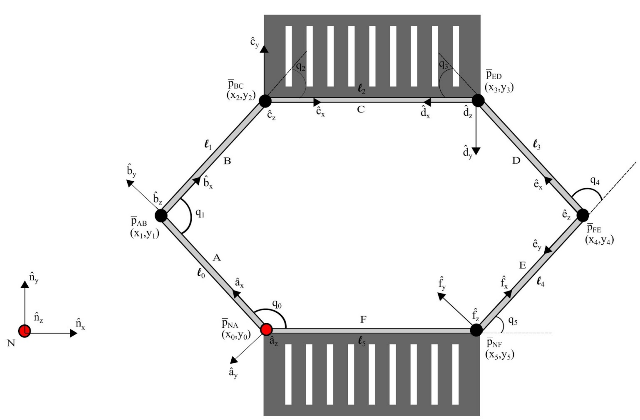


Figure 1. Dynamics model of sarrus link

The aim of the experiment was to track motion of the joint at pAB (shown in figure above) using the software called 'Tracker' [4] and to collect data from the motion. The data is then used in a python program to generate plots.

EXPERIMENT SETUP

Aim:

To create a model of the sarrus link and capture its motion as video.

Materials used:

1. Cardboard
2. Scissors
3. Tape
4. Needle and Thread
5. Coloured paper (orange)
6. Plain paper
7. Stapler
8. Smartphone with video capability
9. Glue

Preparation:

1. Cut the cardboard into a 39cm long strip, with a 3cm width.
2. Cut the coloured paper into three small squares.
3. Fold and tie two long pieces of thread into two thicker strings

Procedure:

1. Mark the long piece of cardboard at regular intervals of 6.5cm each, until six intervals are obtained.
2. These are the six links of the Sarrus link to be modelled
3. Bend the strip at the marked points.
4. Join the ends of the strip with tape to create a sarrus link.
5. Make small holes in the top and bottom links that are relatively vertical to each other.
6. Insert the thread through the holes to connect the top and bottom holes to each other.
7. Place needles on the top link to prevent the threads from slipping.
8. Glue the three orange squares on points pNA, pNF and pAB (shown in figure above). The points pNA and pNF create the base frame.
9. Attach the link to plain paper by stapling them together, make sure the paper does not cover the holes at the bottom.
10. Fix the apparatus on the table with tape.
11. Pull both strings and release them to create an up-down motion of the top link.
12. Capture this motion by taking a video.

Assumptions

The base frame is fixed and rigid.
The links are rigid.
The mass of the needles is neglected.
The joints are all the same, including the joint that was taped.
Friction between threads and cardboard is neglected.

Results

The captured video is run through the software, 'Tracker'. The point mass is placed at the joint pAB.
The distance between the points in the base frame (pNA, pNF) is measured to be 7cm.
The distance measured between the lens of the camera and the experiment setup is 30cm.

Since the joint was moved manually, there is no damping observed in the data plotted from the point mass (Figure 1.b).
The plot shown in Fig 1.b is based on the x and y values obtained by the tracker. A part of the huge table of values is shown in Fig 1.c
The data from the table from the tracker software is used to plot data such as time vs x and time vs y (shown in figures 1.d, 1.e)

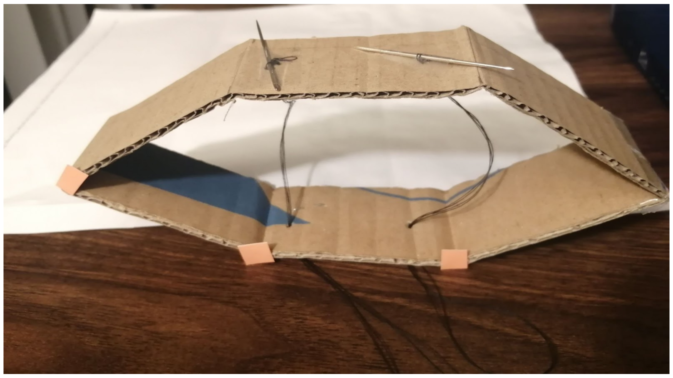


Figure 1.a. Experimental Setup

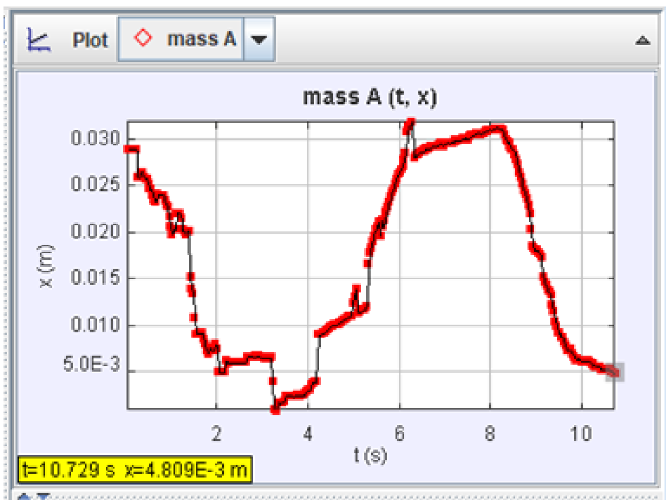


Figure 1.b. Plot of the motion of the joint

Table | mass A

t (s)	x (m)	y (m)
0.033	2.898E-2	6.303E-2
0.066	2.896E-2	6.300E-2
0.098	2.895E-2	6.297E-2
0.131	2.898E-2	6.285E-2
0.164	2.899E-2	6.279E-2
0.197	2.896E-2	6.278E-2
0.230	2.893E-2	6.270E-2
0.262	2.589E-2	6.412E-2
0.295	2.589E-2	6.396E-2
0.328	2.651E-2	6.408E-2
0.361	2.651E-2	6.407E-2
0.394	2.586E-2	6.451E-2
0.427	2.582E-2	6.445E-2
0.459	2.582E-2	6.449E-2

Figure 1.c. Table showing a portion of the time and xy position of the joint

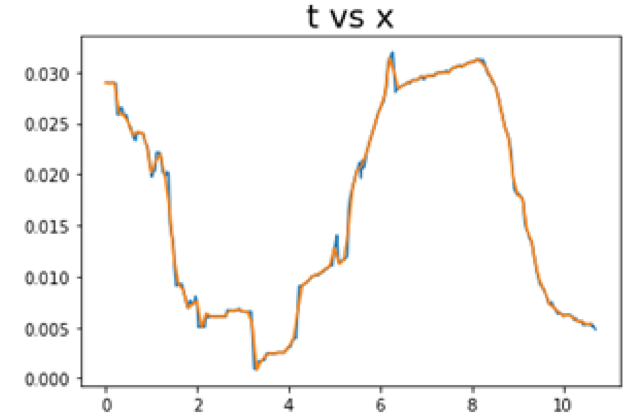


Figure 1.d. Plot of Time vs x axis

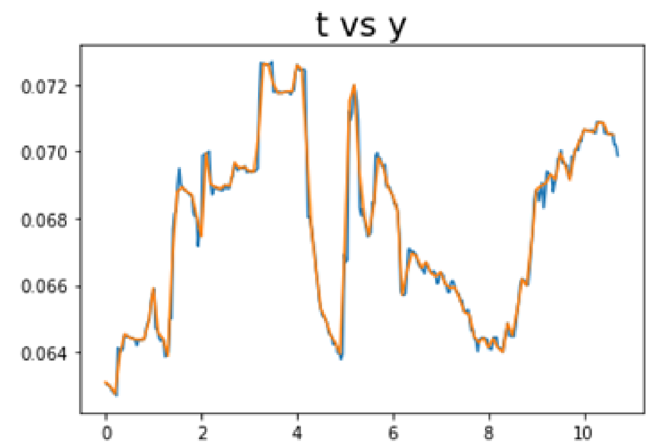


Figure 1.e. Plot of Time vs y axis

```
In [1]: import pandas as pd
        import numpy
        import matplotlib.pyplot as plt
        import scipy.interpolate as si

        df=pd.read_csv(r'C:\Users\Febaraju\Documents\data1.csv', sep=',')

        x = df.x.to_numpy()
        y = df.y.to_numpy()
        t = df.t.to_numpy()


        xy = numpy.array([x,y]).T
        f = si.interp1d(t,xy.T,fill_value='extrapolate',kind='quadratic')
        new_t = numpy.r_[0:t[-1]:.1]

        plt.figure()
        plt.title('t vs x',fontsize = 20)
        plt.plot(t,x)
        plt.plot(new_t,f(new_t)[0])

        plt.figure()
        plt.title('t vs y',fontsize = 20)
        plt.plot(t,y)
        plt.plot(new_t,f(new_t)[1])
        plt.figure()
        plt.title('x vs y',fontsize = 20)
        plt.plot(x,y)
```

Figure 1.f. Snippet of the code used for plotting time vs x and time vs y

2. Actuator Fitting

The team is using a compression spring in combination with a servo motor as the main actuation method of the system. Custom three-dimensional printed PLA parts will be used to house the spring and motor relative to the cardstock sarrus mechanism. The design is simple, easy to assemble, and customizable to multiple design and spring types. The sarrus link dimensions that the team decided to use is shown below in Figure 2. The figure depicts the top and bottom links of the sarrus mechanism to be two inches by two inches. Using these dimensions, three-dimensional parts were printed and shown in Figure 3. These parts will keep the top and bottom links stiff in order to allow for contraction and expansion using a spring. The spring is inserted in between these parts and a lock pin holds the parts together. A small hole in the two parts allows for the addition of a string. This string will be used to contract the spring with a servo motor. The assembled system is shown in a CAD rendering to emphasize hidden details (see Figure 4).

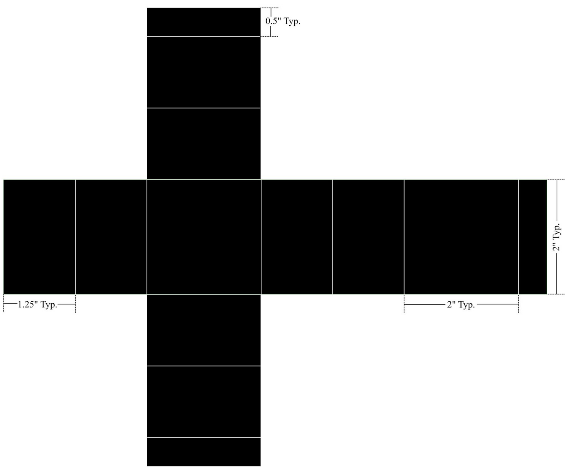


Figure 2. Two Dimensional Cardstock Sarrus Outline

Figure 3. Three Dimensional PLA Printed Parts

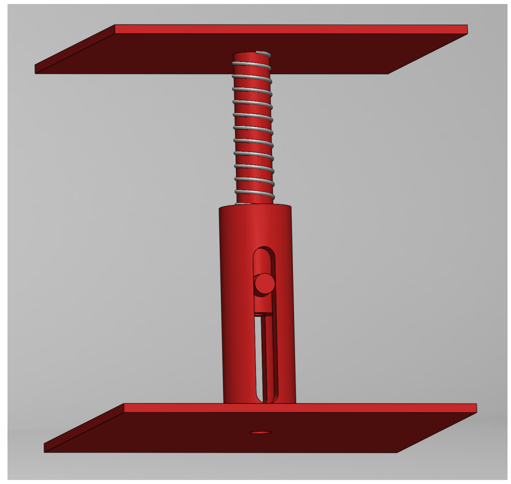
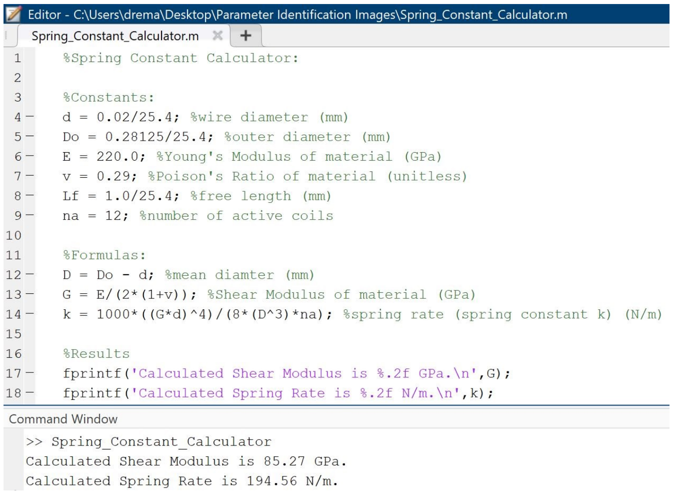


Figure 4. CAD Rendering of Assembled Printed Parts

In order to keep the sarrus link close to its fully extended position at rest, the three dimensional printed parts have a height of 2.250 inches. As seen in Figure 2, with two side links of 1.250 inches, the max height the sarrus link can extend to is 2.500 inches. The team does not want the system to fully extend. As a result, the assembled printed parts have a height 0.250 inches shorter than the sarus mechanisms max height. The team temporarily selected two compression springs with a combined starting height of 1.000 inches. They were selected because of the low spring constant (based on physical resistance). This will allow for easy compression which a servo can achieve without overcurrent limitations. When fully compressed, the two springs have a combined height of 0.2800 inches. Each spring has six active coils and eight total coils, where the other two are used to close the ends of the spring. We assume the springs are made of zinc-coated steel (ASTM A591 Zinc Coated Steel, Commercial) [2]. The outer diameter of the springs are 0.28125 inches. Additionally, the wire diameter is 0.02 inches.

Unfortunately, the springs used by the team did not have a manufacturer spring constant. As a result, the team had to calculate this value using physical testing. Using the spring information from above, and the formulas described below, the team was able to calculate the combined springs rate of the two springs used (k).

Using MATLAB, the team declared all of the known variables. Then the team used three additional formulas to calculate the spring rate (k) [3]. Figure 5 shows the code used and the resulting k value of 194.56 Newtons per meter. To further confirm these calculations, the team physically compared the displacement versus force of the system using Hooke's Law. As shown in Figure 6, the team used a scale and ruler to gather data on the springs displacement relative to the force applied. Figure 7 shows a plot of the physical test results including the spring constant (k) and the elastic potential energy. Taking the average of the physical testing and theoretical calculations, we conclude that the spring constant is approximately 200.45 Newtons per meter.



```
Editor - C:\Users\drema\Desktop\Parameter Identification Images\Spring_Constant_Calculator.m
Spring_Constant_Calculator.m

%Spring Constant Calculator:

%Constants:
d = 0.02/25.4; %wire diameter (mm)
Do = 0.28125/25.4; %outer diameter (mm)
E = 220.0; %Young's Modulus of material (GPa)
v = 0.29; %Poison's Ratio of material (unitless)
Lf = 1.0/25.4; %free length (mm)
na = 12; %number of active coils

%Formulas:
D = Do - d; %mean diamter (mm)
G = E/(2*(1+v)); %Shear Modulus of material (GPa)
k = 1000*((G*d)^4)/(8*(D^3)*na); %spring rate (spring constant k) (N/m)

%Results
fprintf('Calculated Shear Modulus is %.2f GPa.\n',G);
fprintf('Calculated Spring Rate is %.2f N/m.\n',k);

Command Window
>> Spring_Constant_Calculator
Calculated Shear Modulus is 85.27 GPa.
Calculated Spring Rate is 194.56 N/m.
```

Figure 5. MATLAB Spring Constant Code

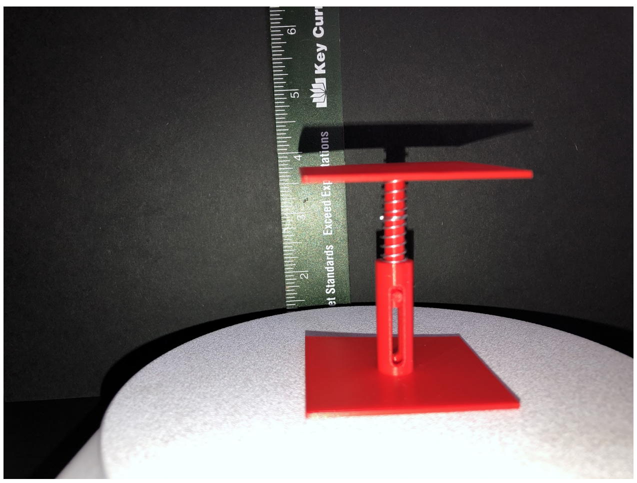


Figure 6. Physical Spring Constant Test Setup

Initial Length (m)	Final Length (m)	Displacement (m)	Force (N)	Spring Constant (N/m)	Average Spring Constant (N/m)
0.0254	0.0254	0	0	-	**206.3429571**
0.0254	0.01905	0.00635	1.121	176.5354331	
0.0254	0.0127	0.0127	2.589	203.8582677	**Average Elastic PE (J)**
0.0254	0.00635	0.01905	4.546	238.6351706	**0.037441188**

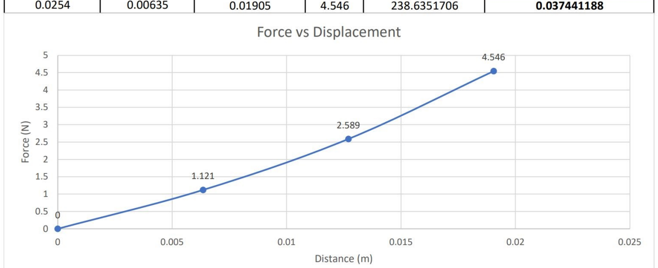


Figure 7. Resulting Plot of Physical Spring Constant Test

From the tests executed above, the team was able to spec a motor capable of providing the necessary force needed to fully compress the spring. With a spring constant of approximately 200.45 Newtons per meter and a max displacement of 0.01905 meters, we get a resultant force of 3.8186 Newtons using Hooke's Law. We know that load torque is equal to force (F) multiplied by the distance (r) between the center of rotation and the force point. Assuming the team prints a three dimensional pulley with a radius of 0.00635 meters, the maximum torque required by the motor is 0.0242 Newton-meters. A common micro servo has a stall torque of 2.1 kilogram-centimeters at 4.8 volts. This equates to about 0.21 Newton-meters which is almost nine times the required force we need to compress the systems springs. As a result, the team decided to spec Adafruit's MG90D Metal Gear Micro Servo shown in Figure 8. This 22.8 by 12.2 by 28.5 millimeter servo can accept an input voltage anywhere from 4.8v to 6 volts DC.

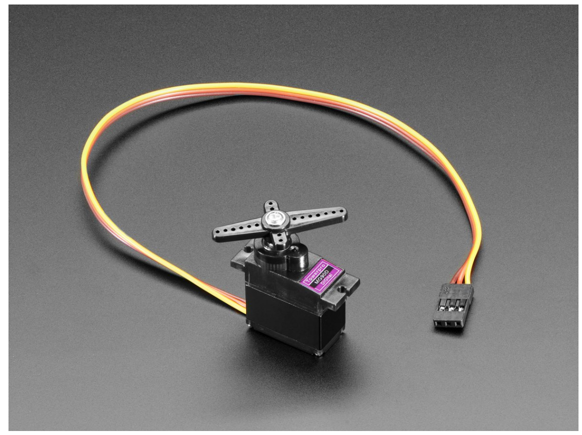


Figure 8. Adafruit's MG90D Metal Gear Micro Servo [1]

3. Cantilever Beams Process

One material the team is considering using is corrugated cardboard. This material is both thicker and sturdier than cardstock. To test the stiffness of this material, a cantilever beams process was performed.

Materials used:

1. 4 rectangular strips of cardstock of the same size (25 mm x 125 mm)
2. Clamp
3. String
4. Adhesive, such as tape
5. Various masses; The masses used by the team can be seen below in Figure 9

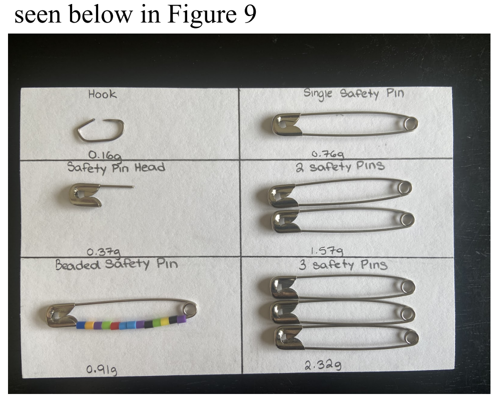


Figure 9. 6 masses used for loading the samples, with no sample being greater than 3g

Procedure [5]:

1. Prepare the 4 strips of material, one of which will be the base, and three of which will be the samples from which masses will be hung (Figure 10)

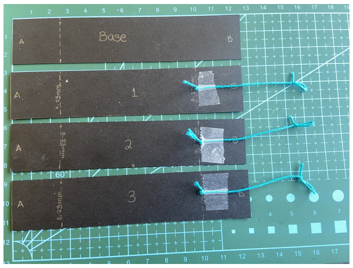


Figure 10 The base and 3 samples

2. Measure the thickness of each sample at 2 separate locations.
    a. Each sample was measured 25mm from each end and resulted in the same value of 0.23mm with each measurement
3. Tape a string to the top of each of the samples as a loop from which to hang the masses. (Figure 10)
    a. The strings were weighed and did not register on the gram scale.
4. Clamp the base material and one of the sample materials such that 100mm is hanging off the edge of the table or counter it was clamped to. As seen in Figure 11.

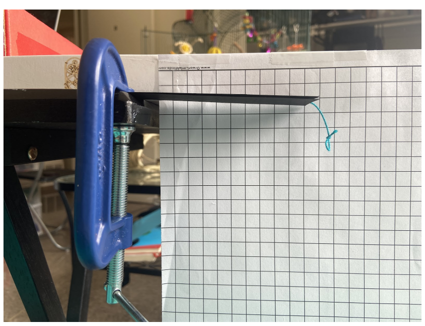


Figure 11. Sample 1 clamped with the base to the table

5. Mount a camera in front of the beam in a stable location to take multiple pictures across tests
6. Take a picture of the unloaded beam, obtaining a picture similar to that of Figure 11.
7. Load the sample with the masses (Figure 9) one at a time, measuring the deflection of the sample with respect to the base, taking a picture of each load. An example of this can be seen below in Figure 12.

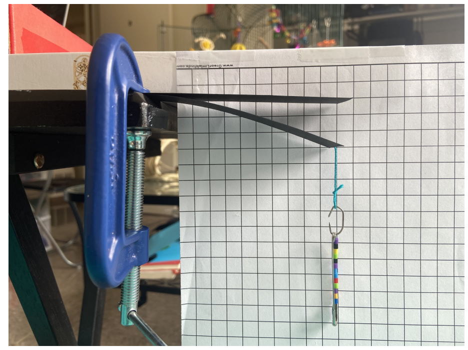
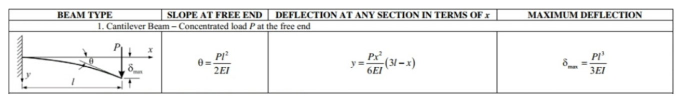


Figure 12. A mass loaded onto sample 1

8. Repeat the test for the other 2 samples

Results:

The deflection tests use the equations found in Figure 13. Looking at the maximum deflection equation, it can be seen that all values are easily measurable given the test setup above (Figure 11), leaving only Young's Modulus (E) to for calculation. From there, the team can reorder these equations so that it is solving for E, as seen in Figure 12, assuming I is equal to that in Figure 13.



BEAM TYPE	SLOPE AT FREE END	DEFLECTION AT ANY SECTION IN TERMS OF x	MAXIMUM DEFLECTION
1. Cantilever Beam – Concentrated load P at the free end			
	$\theta = \frac{Pl^2}{2EI}$	$y = \frac{Px^2}{6EI}(3l - x)$	$\delta_{max} = \frac{Pl^3}{3EI}$

Figure 11. Equations used to calculate young's modulus [5]

$$E = \frac{PL^3}{3dI}$$

Figure 12. Young's Modulus (E)

$$I = \frac{bh^3}{12}$$

Figure 13. The given equation for I

To use these equations, the data from the tests had to be compiled, which can be found in Figure 14, which is the deflection of the sample from the base, removing the initial deflection that had occurred due to imperfections in the material. The masses labeled 1-6 in Figure 14 are labeled in Figure 15.

Cardstock Deflection from the Base						
	Deflection (m) from base without initial deflection					
Sample	1	2	3	4	5	6
1	0.00294	0.01302	0.02371	0.02798	0.04231	0.055
2	0.00302	0.01395	0.02411	0.02903	0.04281	0.05557
3	0.00191	0.01285	0.02422	0.02743	0.04366	0.05779
Average	2.62E-03	1.33E-02	2.40E-02	2.81E-02	4.29E-02	5.61E-02

Figure 14. Data of the deflection of each mass on each sample.

Loads and weights		
Load	Item	Weight in kg (with hook)
1	Hook	0.00016
2	Safety Pin Head	0.00053
3	1 Safety Pin (empty)	0.00092
4	Beaded Safety Pin	0.00107
5	2 Safety Pins (empty)	0.00173
6	3 Safety Pins (empty)	0.00248

Figure 15. Masses in kg

A visual representation of the deflection over the mass can be found in Figure 16. It can be seen that there is a quadratic relationship between the two values.

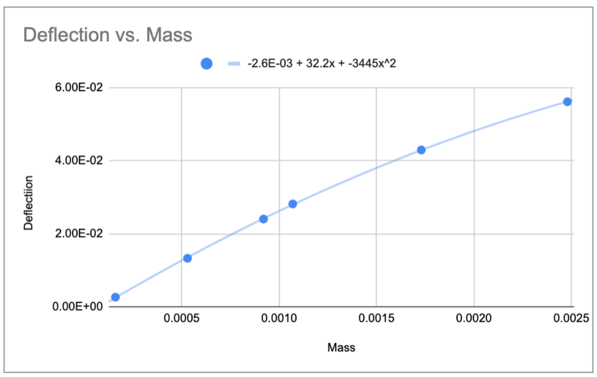


Figure 16. Graph of deflection over mass

With the data from Figures 14 and 15, using the equations to Find E, the team was able to calculate the average Young's Modulus for the material, which came out to be 6.98e3 N/M^2.

4. Euler-Bernoulli Beams Code

The entirety of the Euler-Bernoulli Beams code can be found in the Dynamics II section of the code. The end of the code can be found below in Figure 17.

```
[ ] subs[x]=sol.x[0]
    d2.subs(subs)
    q2.subs(subs)

    0.0542171836310331
```

Figure 17. Some of the Euler Bernoulli Beams Code Results

5. System Level Prototype

The team's mechanical design consists of three sarrus mechanisms placed on top of one another vertically as shown in Figure 18. The sarrus mechanisms are made from cardstock material and the spring/support system is made from PLA printed parts. When stationary, the compression springs will force the sarrus mechanisms to hold an expanded position as shown in Figure 19. On the other hand, when the servo motors are activated, the spring is compressed and the sarrus mechanisms translate in the negative y-direction and expand in the positive and negative x-directions as shown in Figure 20. This will allow for the mechanism to anchor to nearby walls similar to the way a razor clam anchors to nearby sand with its "foot". For testing purposes, the team used their hand force to pull on a string in place of a servo motor and pulley. The team chose three sarrus links in order to allow the mechanism to translate vertically in the following manner:

1. All sarrus mechanisms will begin motion in an extended position, with the spring mechanism forcing the sarrus link open.
2. The top-most sarrus mechanism will use a servo motor to contract the spring and expand its links in both the positive and negative x-direction. This will lock the mechanism into place with the surrounding walls as shown in Figure 21.
3. The middle sarrus mechanism will then contract its spring in order to pull the bottom-most link upwards.
4. The bottom-most sarrus mechanism will then contract its spring in order to lock itself against the surrounding walls.
5. The middle and top-most sarrus mechanisms will then expand their springs in order to unlock from the surrounding walls and move upwards.
6. Then the mechanism recycles the process starting with step two. This will allow for the system to translate in an upward or positive y-direction.

In order to achieve this motion, each sarrus mechanism is controlled by a separate motor to allow for individual control of each link. Eventually, an electrical housing box will screw into the bottom plate of the spring mechanism seen in Figure 4. This housing will hold the servo motor and pulley.

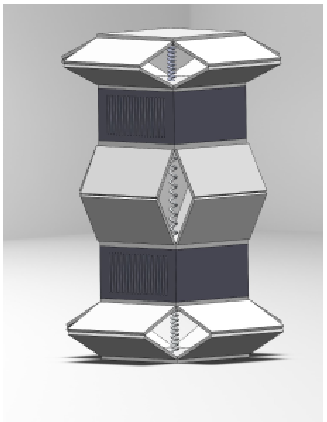


Figure 18. Three Sarrus Mechanism CAD Model

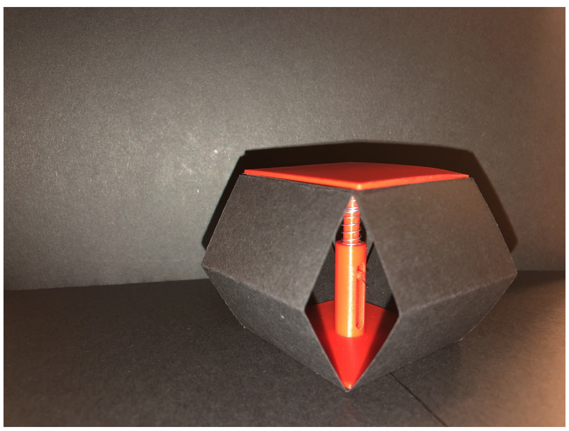


Figure 19. Sarrus Mechanism at Rest

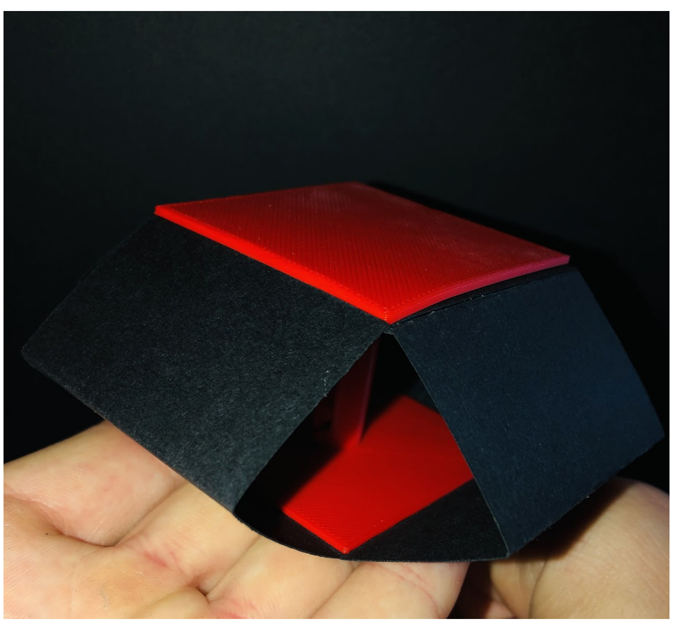


Figure 20. Sarrus Mechanism Contracted

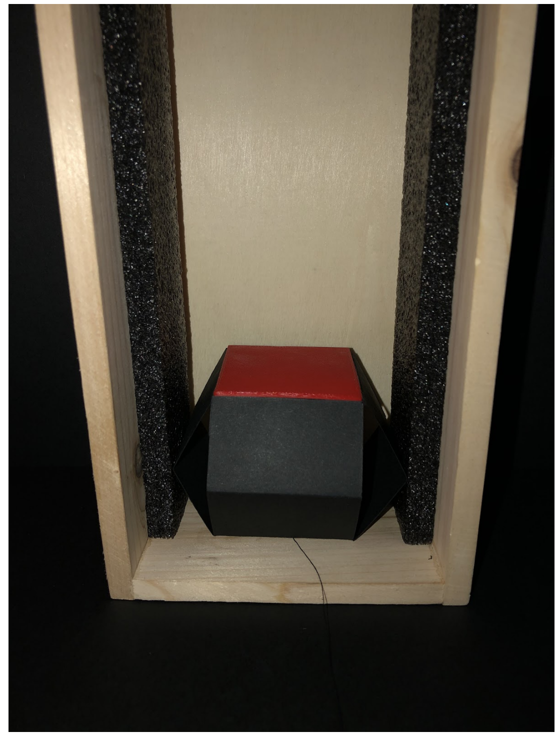


Figure 21. Sarrus Mechanism Anchored to Walls

7. Contributions

All team members contributed to the research discussed throughout this report. Specifically, Feba Raja Abraham extracted data from a motion capture of our mechanism. Andrei Marinescu created a system-level prototype and developed a model for our actuator. Charlotte Deming modeled our systems link stiffness via Cantilever Beams tests. She also wrote and ran the Euler-Bernoulli Beams code on our mechanism.

References

[1] A. Industries, "Micro Servo - MG90D High Torque Metal Gear," *adafruit industries blog RSS*. [Online]. Available: https://www.adafruit.com/product/1143. [Accessed: 08-Mar-2021].

[2] "The Online Materials Information Resource," *MatWeb*, 1996. [Online]. Available: http://www.matweb.com/search/datasheet.aspx?matguid=af58cf14010141b1a1cd94def4826389&ckck=1. [Accessed: 08-Mar-2021].

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Available:https://egr557.github.io/modules/compliance/generated/prbm.html[Accessed: 08- Mar-2021]