Habitat's Airlock Linkage System

Engineering Design I: Skills and Methods

24-370

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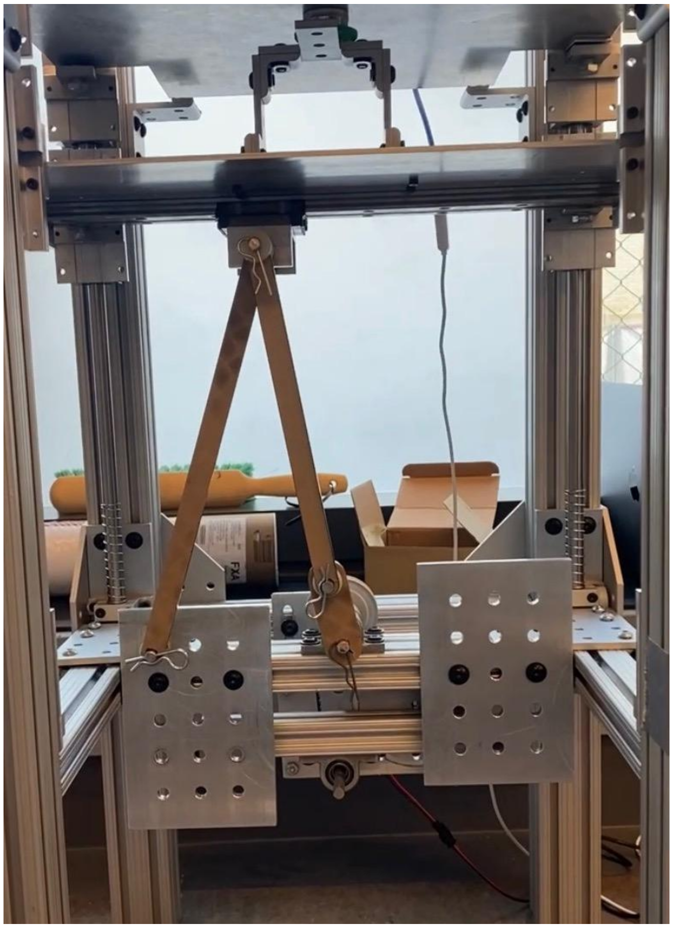
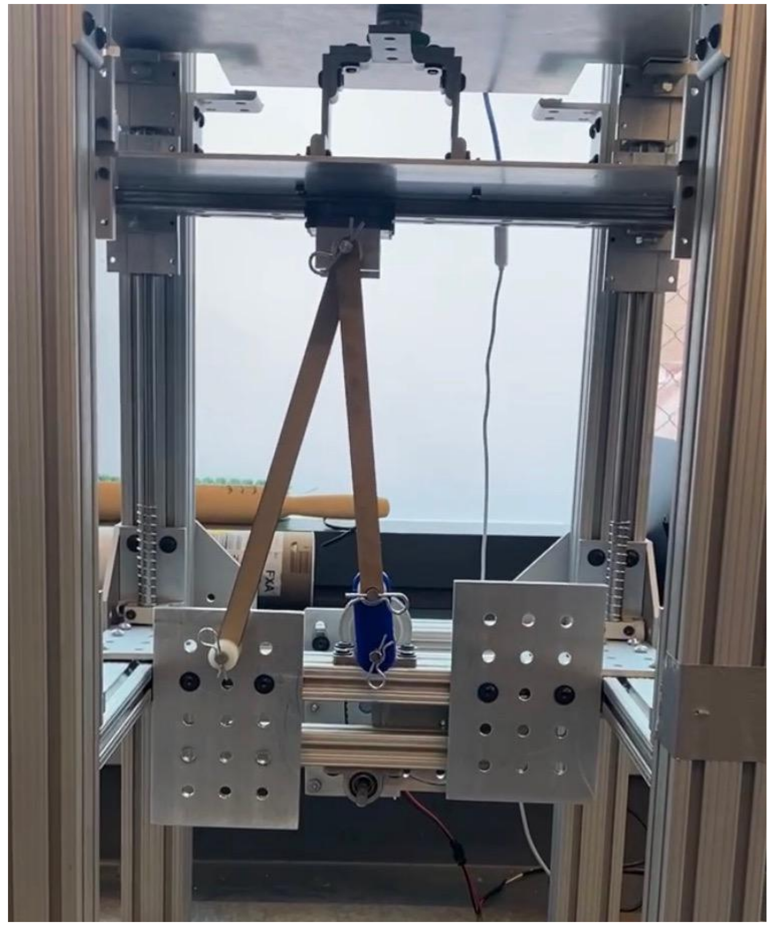
Date Submitted:
3/3/2023

Summary



Intermediate Testing



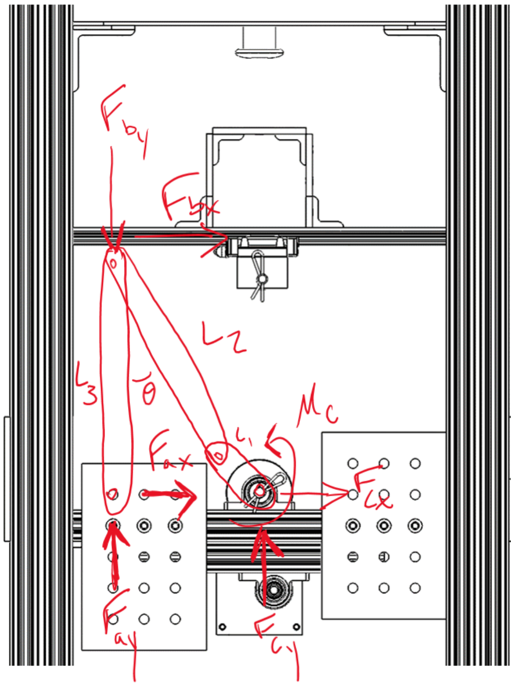
Final Testing Day

The theoretical button press time for our intermediate testing was 30 seconds, while the experimental button press time ended up being 27.55 seconds. We did not change our linkage system from our intermediate testing to our final testing, so our theoretical button press time for our final testing was also 30 seconds. However, our experimental button press time ended up being only 25.91 seconds for our final testing. This difference was due to our group accidentally setting up our rocker in the wrong position. We mistakenly connected the rocker to the top-middle pin instead of the top-left pin, which is shown in the picture above.

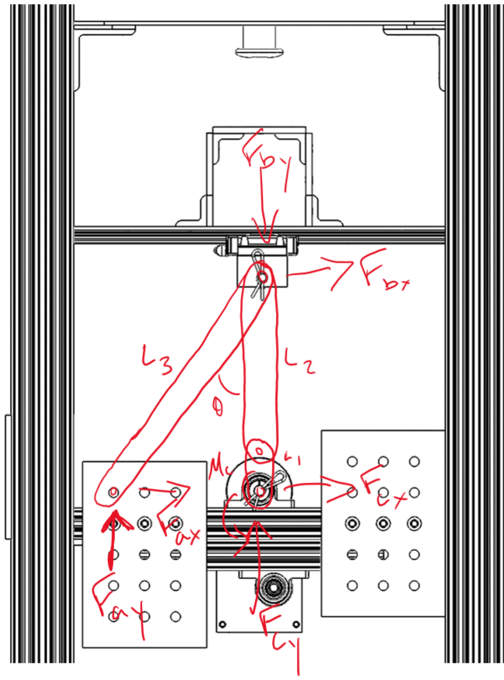
Our group made two improvements from initial testing to final testing. Our first improvement was to fillet the edges of our hexagonal hole, which allowed the stress concentration at the hexagonal pin hole to be reduced due to the elimination of sharp edges. This greatly reduced the chances of fractures forming at that hole. Our second improvement was optimizing the mass of our linkage system. We decreased our mass from 221.33 grams to 61.0 grams, a percent decrease of 72.4%. These improvements allowed our button press time over mass ratio to improve from .127 to .424!

Brainstorming

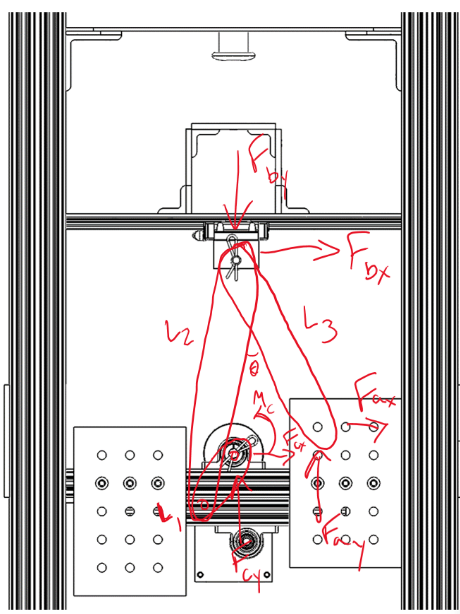
Our initial design ideas utilized single hole design rather than the slotted hole design. This decision was made to simplify the design by decreasing the number of places where unknowns could affect the design. Below are sketches of 6 initial potential designs



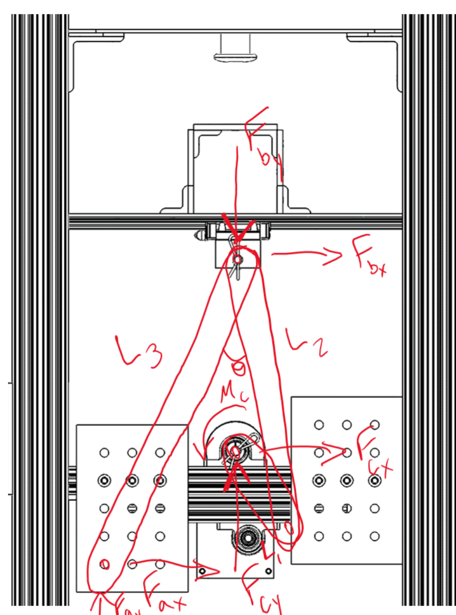
$L_3 > L_2 > L_1 \quad \theta < 45^\circ$



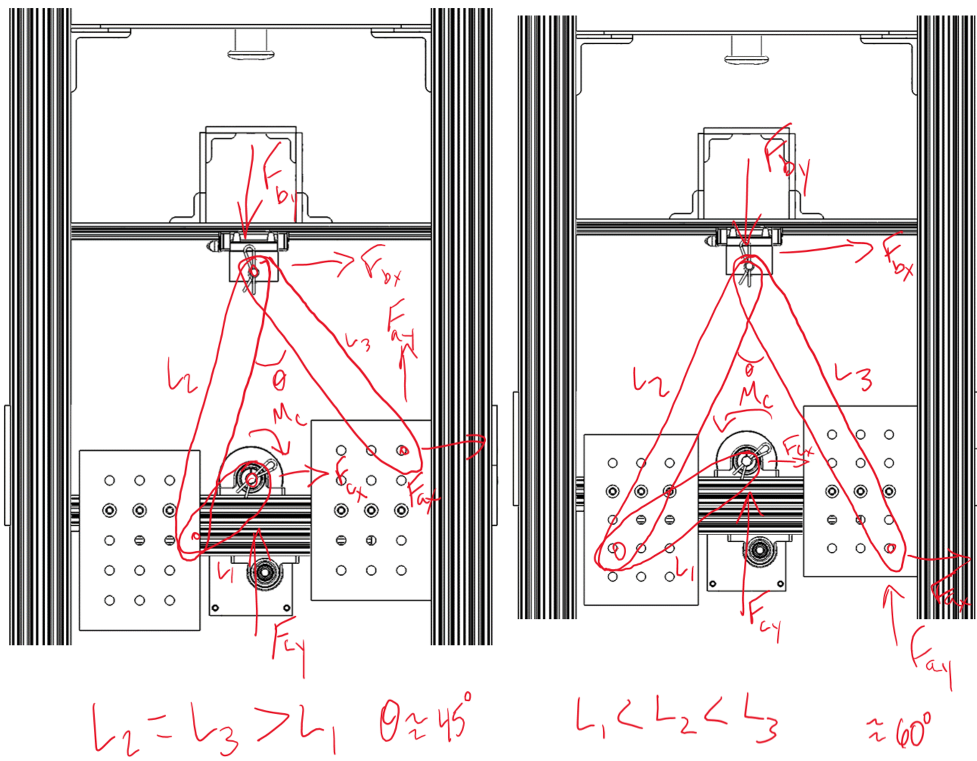
$L_3 > L_2 > L_1 \quad \theta < 45^\circ$



$L_2 > L_3 > L_1 \quad \theta < 45^\circ$



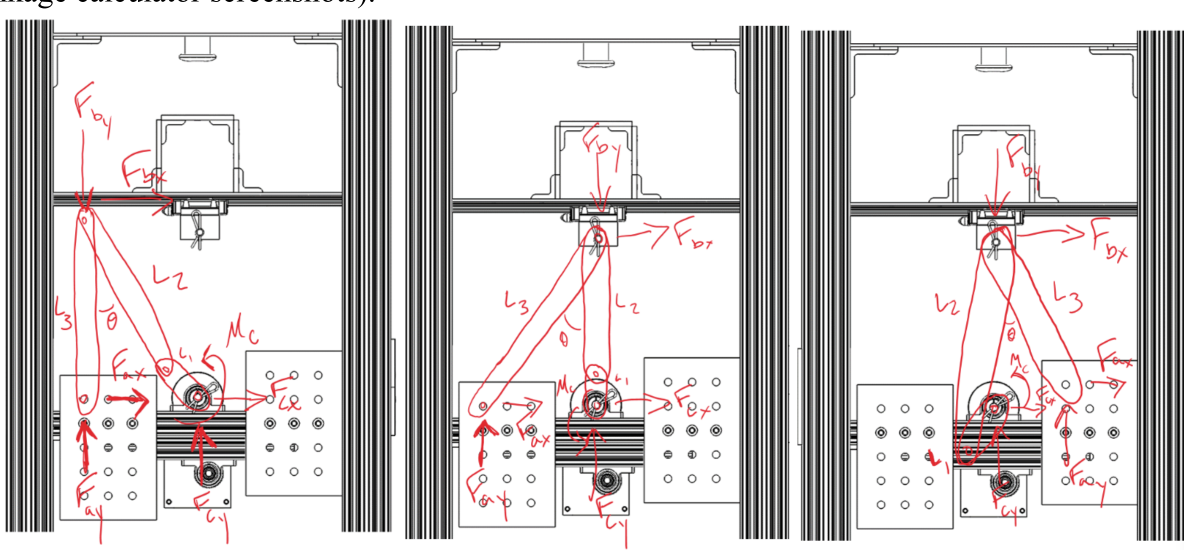
$L_3 > L_2 > L_1 \quad \theta < 45^\circ$



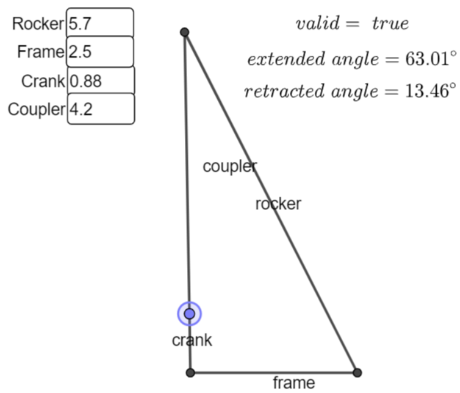
We have selected the first three drawings to proceed with. The others have a very high potential for the slider to hit the sides of the rail and fail the test. The three designs that we selected have the best geometry and should be able to hit the button without hitting the stoppers on the sides of the rail.

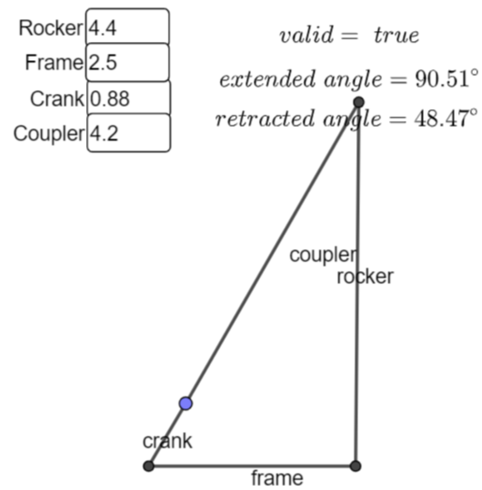
Early Ideation

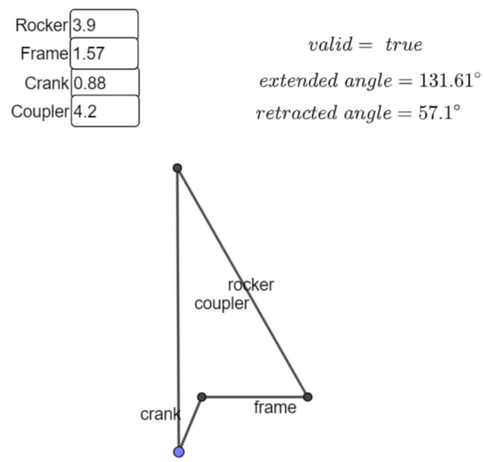
We narrowed down our search to the three designs below (link lengths are given in the linkage calculator screenshots).



We then placed these designs in an online linkage calculator to get a better understanding of the geometry and likelihood of fitting in the linkage system.





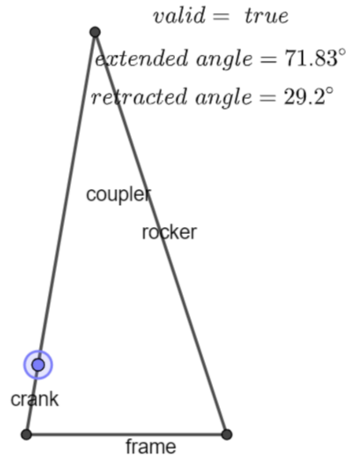


Note: Due to the limitations of the online calculator, the actual linkage lengths are 2x those in the diagrams (in inches). Additionally, the third linkage would be rotated 17 degrees counterclockwise on the actual assembly.

The estimated button press times from the online linkage calculator for the three designs above were 90 seconds, 30 seconds, and 90 seconds respectively. However, due to geometry issues and the constraints of the assembly, we made some changes to these designs to create our final design. The final design we chose was a combination of the first two linkage screenshots shown above. This created a design that had very good geometry for the test to stay within the bounds of the assembly and strong estimated button push time of 30 seconds while still being simple enough to minimize the possibility for unanticipated variables to affect the outcome. The final design is shown below.

- Crank - 1.75in
- Coupler - 8.4in

- Rocker - 10.56in



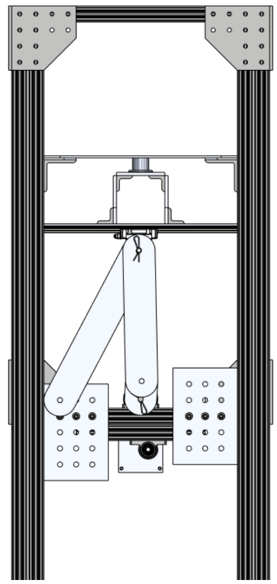
Stress Analysis

The three orientations chosen and the corresponding hand calculations for the chosen orientation are shown below. The first orientation shown was identified because this is the instance where the plate height is maximized, resulting in the greatest applied force on the linkage system due to the springs being compressed the most. The second orientation shown was identified because this would be the point where the motor would be causing significant bending stress on the crank and the coupler would be most susceptible to buckling. The third orientation was identified because this position shows where the crank would be most susceptible to buckling as it is completely vertical. Altogether, the first orientation was chosen to conduct stress analysis as we expected this position to be where the system would be under the most stress.

Though our hand calculations showed this was a very conservative choice, we chose to use quarter inch thick acrylic and a width of two inches for each link. We wanted to ensure success on our first test, so we utilized a high factor of safety because our calculations did not account for the weight of the links, contact stresses, dynamic loading, or friction in the plate slider that would cause an increased external force on the system. Ensuring success on our first test now allows us to focus on pure optimization for tests moving forward. Our hand calculations are shown below:

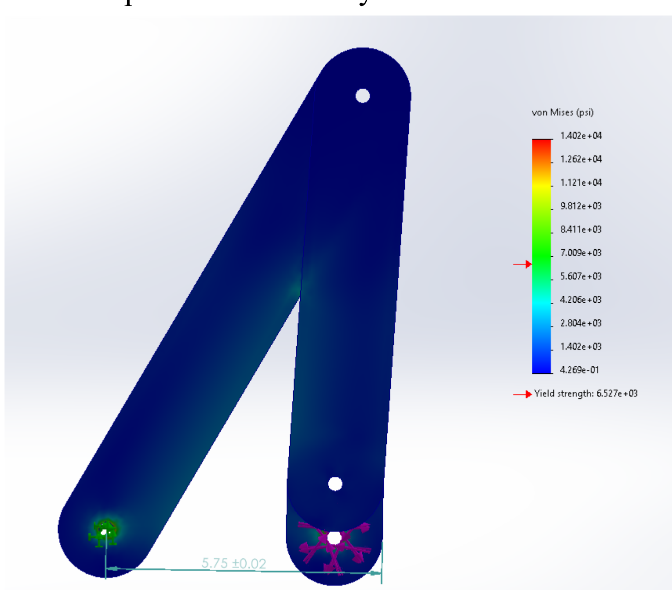
FEA Simulation

For the FEA Simulation, we decided to pick the orientation in which our linkage system would most likely fail and analyze that orientation specifically. This was identified to be when our linkage system was at its greatest height, as illustrated below.

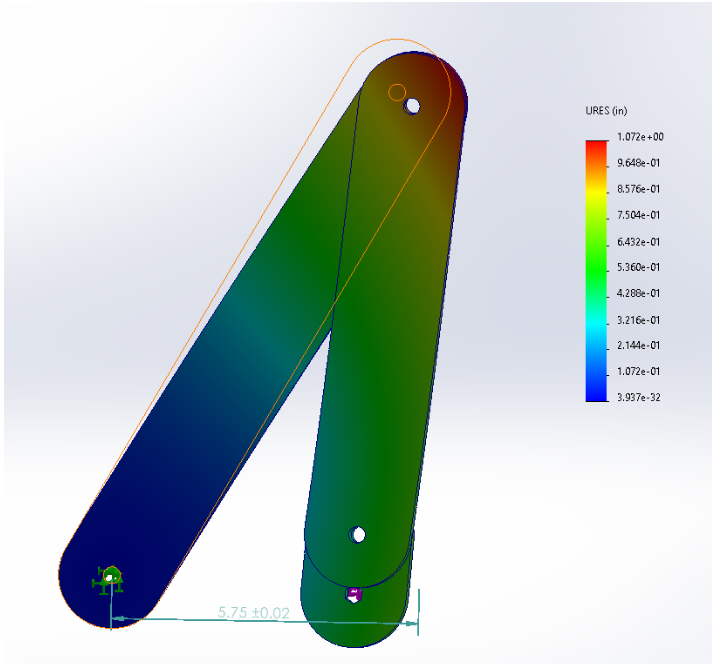


Orientation in Which the Linkage System Would Fail

We chose this orientation because the links would experience the greatest stress due to the presence of both buckling and axial stresses. Furthermore, these stresses would be at their maximum at this current orientation. The FEA Analysis is pictured below, showing the stress concentrations and potential displacement of the system.



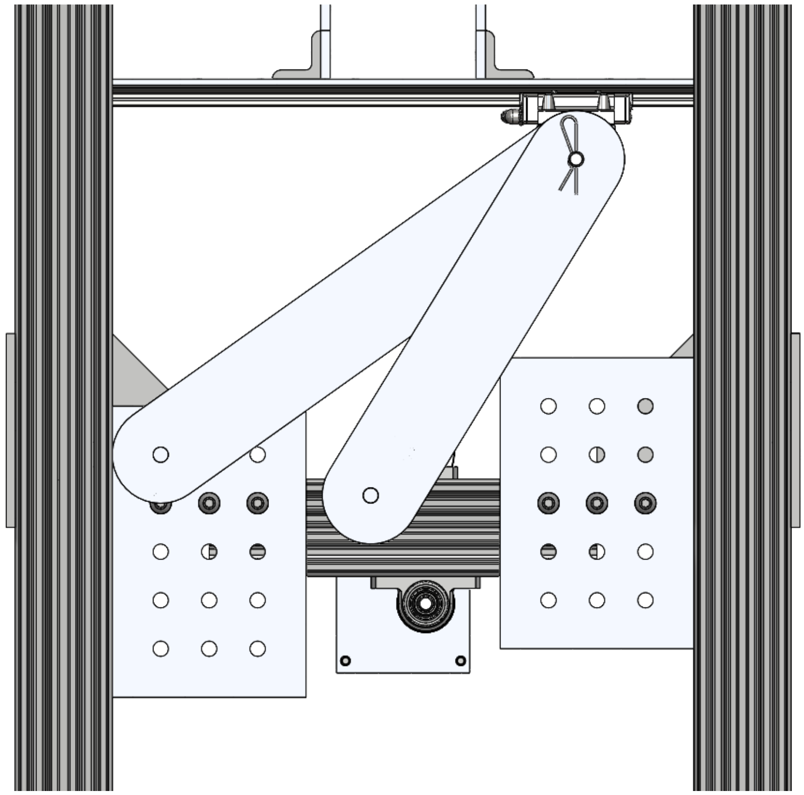
FEA Stress Analysis



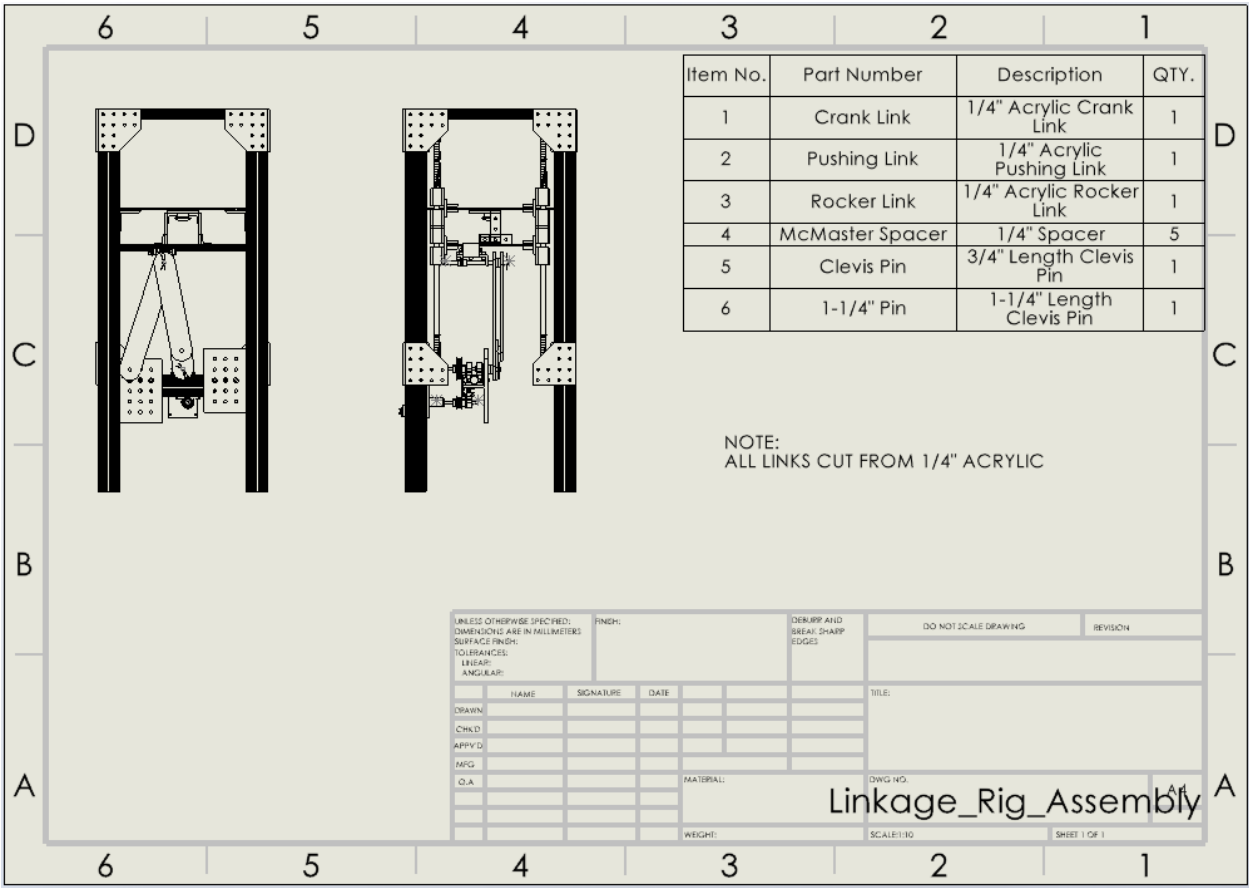
FEA Displacement Analysis

It can be seen from the FEA Analysis that there are very low-stress concentrations along the linkages. The high-stress concentrations are concentrated at the pin connections, with the hexagonal pin connection being the highest. This is very much in line with our stress analysis calculations which predict the linkage system to have a factor of safety of about 16. Furthermore, the linkage system displaces a very small amount further supporting our stress analysis calculations. There is, however, some out-of-plane bending about the hexagonal cut which can be remedied with the use of spacers. Lastly, from the assembly, we estimated that the button would be pushed for about 25% of the time. This translates to about 30 seconds of total button push time.

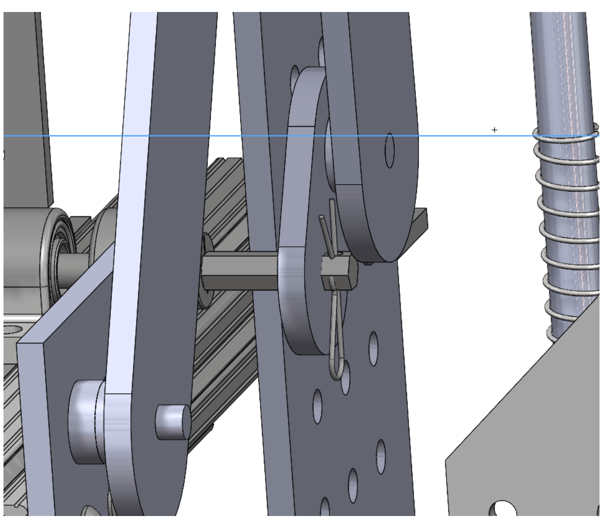
Fabrication and Assembly Practice Day



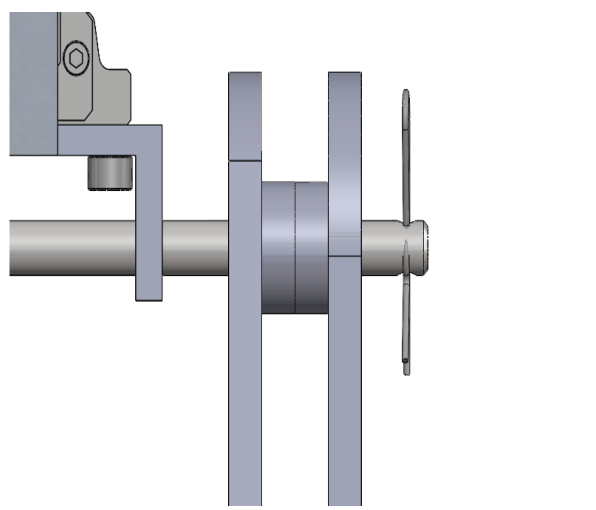
Linkage system in ideal starting position



Item No.	Part Number	Description	QTY.
1	Crank Link	1/4" Acrylic Crank Link	1
2	Pushing Link	1/4" Acrylic Pushing Link	1
3	Rocker Link	1/4" Acrylic Rocker Link	1
4	McMaster Spacer	1/4" Spacer	5
5	Clevis Pin	3/4" Length Clevis Pin	1
6	1-1/4" Pin	1-1/4" Length Clevis Pin	1



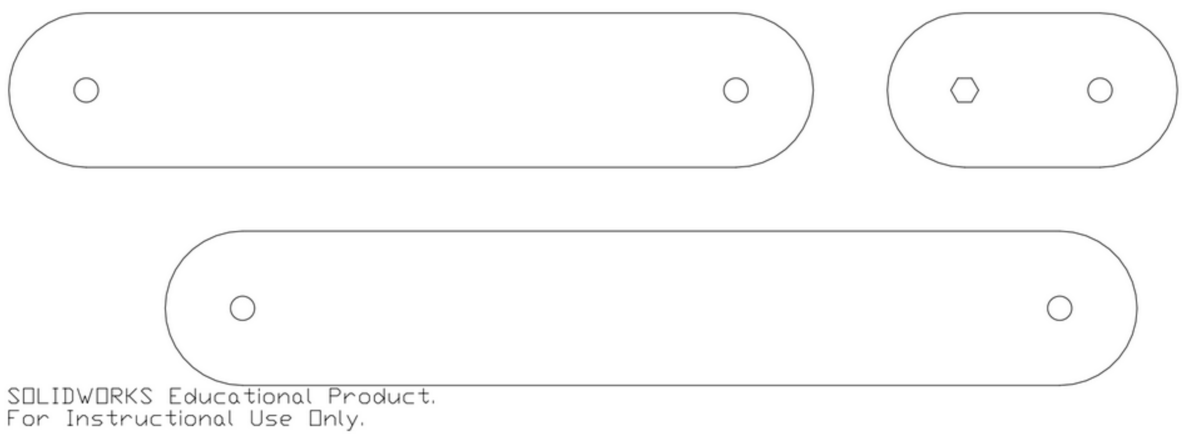
Bottom of System



Top of System

Assembly:

1. Attach crank shaft to crank link
2. Place 1-¼” Pin on peg board in the position specified in the drawing, than place two ¼” washers on pin
3. Attach rocker link to the peg board pin and the platform pin
4. Place two ¼” washers on the platform pin in front of the rocker link
5. Attach ¾” pin to free end of the crank link and place one ¼” washer on the pin
6. Attach the coupler link to the crank pin and platform pin



(Final DXF)

Practice Day Results

Our system achieved a final button press time of 28 seconds and did not fail. We predicted a total button press time of 30 seconds, meaning the system slightly underperformed. This can be explained by a number of factors, the most prominent being that the assembly on the rig was modified on the day of testing. The hexagonal hole connecting the crankshaft to the crank link was cut at an angle to the crankshaft. This means there was significant out of plane positioning of the links (pictured below). Our large factor of safety prevented out of plane bending to be an issue, but by angling the links, their vertical length at any given time during the test was reduced, lowering the total time that the button was pressed.

This problem was compounded by the length of the pins not being filled with washers. The pin used to connect the crank link to the coupler link had to be extended, and there was room between the washers and the link widths, meaning the pin was able to sink (pictured below) further than predicted by our model. This exaggerated the reduction in height caused by out of plane positioning and caused excess twisting in the crankshaft. While our assembly did not fail, these issues reduced the time that the button was pressed and increased stresses past what was expected.

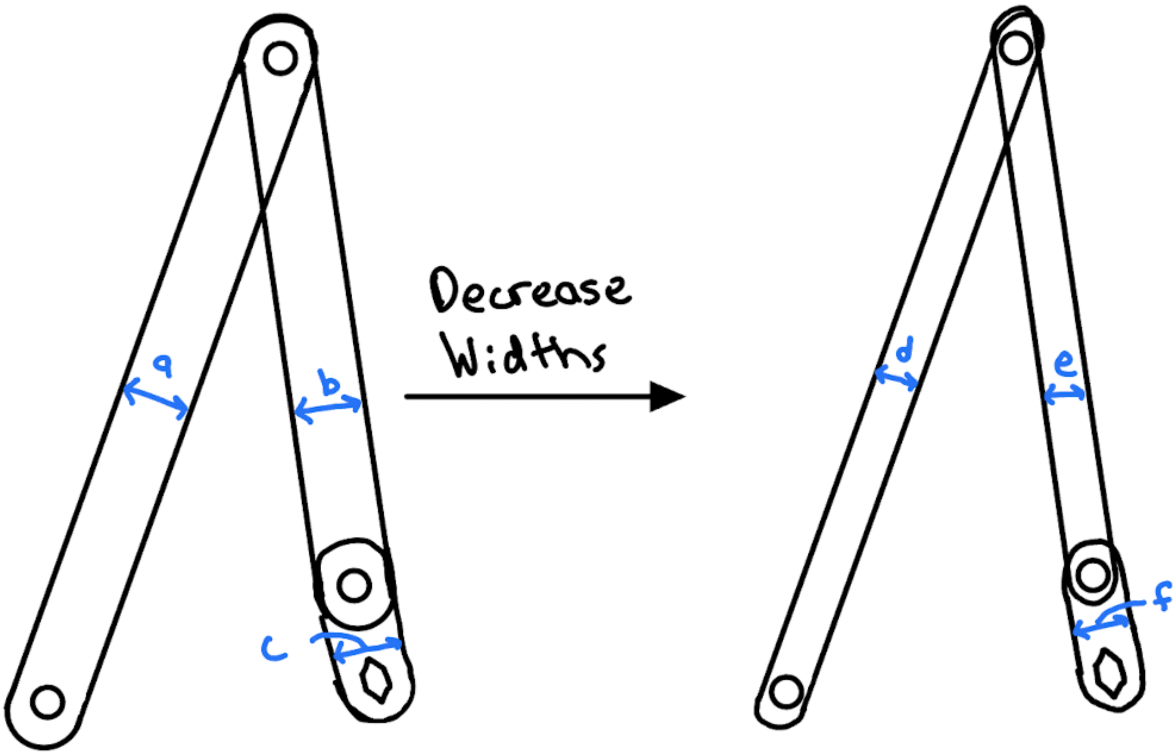
Reflection

Our system performed closely to how we expected it to perform. Our system functioned properly by pushing the button for a time of 28 seconds, maintaining a mass of 221.33 grams, and having a button push time to mass ratio of .127. Our system had a factor of safety roughly equal to 16, so we did not expect it to fail. We did not anticipate the motor to stall as our design aimed to minimize the applied force acting on the system by not pushing the plate up too high. From our motion analysis, we predicted a button push time of 30 seconds, but only had a button push time of 28 seconds which was a small discrepancy possibly caused by deformation in the links. Additionally, the spacer placement we planned to utilize did not turn out to be the proper spacer placement when testing, which was another discrepancy.

Before the next test day, we plan to improve our system by first decreasing the width of our links to values that result in lower factors of safety so the mass of our system can be optimized. The width of the coupler and rocker in our linkage system based on our hand-calculated stress analysis can be decreased significantly, while the crank's width can be decreased as well but not as severely as the rocker and coupler. Second, we plan to fillet the edges of the hexagonal hole in our crank so that stress concentrations there are minimized to reduce the chance of fracture. Lastly, we plan to minimize any out-of-plane bending and buckling that occurred to our linkage system on the first test day by improving our manufacturing (utilizing a cleaner laser cut) and solidifying our spacer locations so that our links are not angled from a right view perspective.

Drawings for the three changes are shown below.

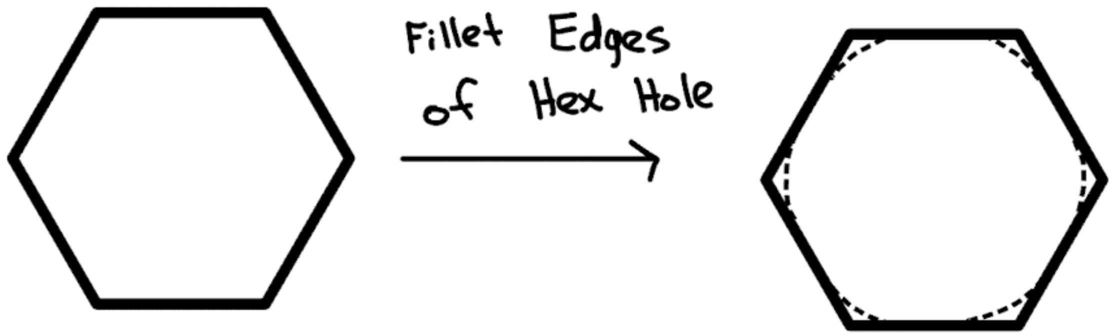
First Change:



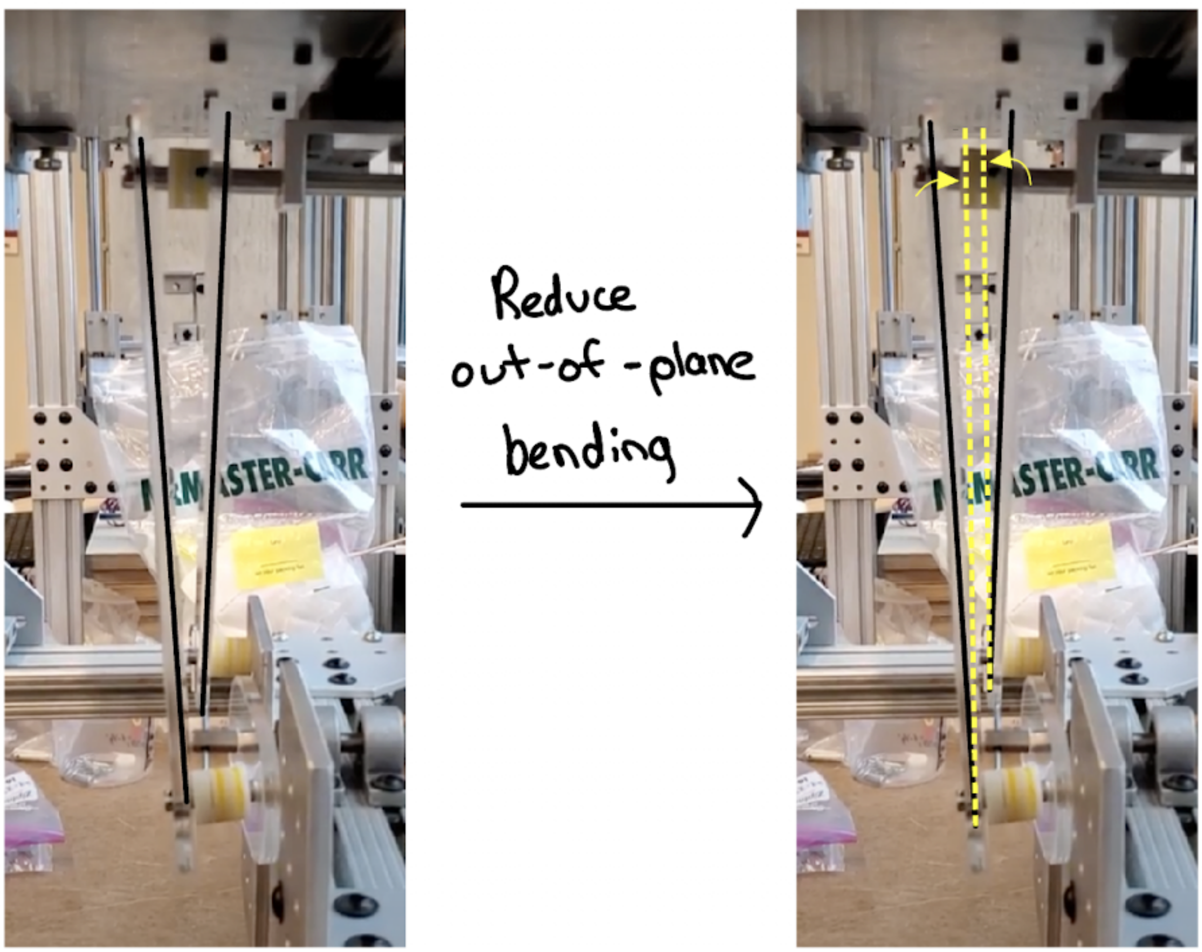
a>d
b>e
c>f

Component	Rocker	Coupler	Crank
Width (in.) for FOS = 1	.018	.022	.485
Width (in.) for FOS = 2	.036	.044	.687

Second Change:

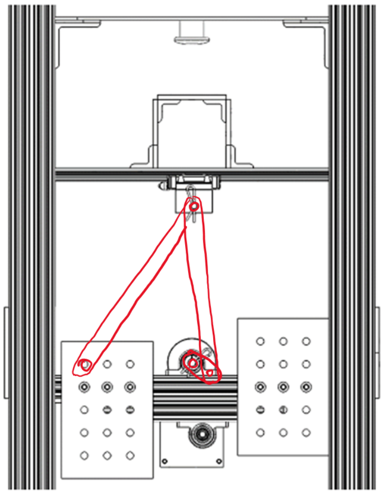


Third Change:

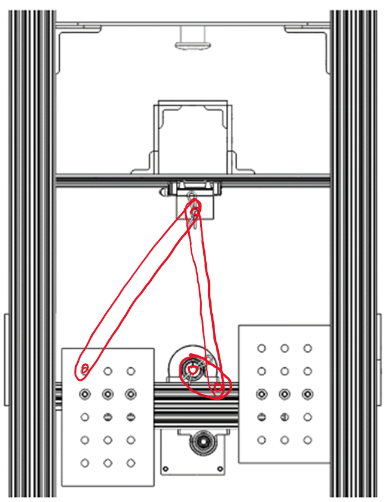


Iterative Ideation

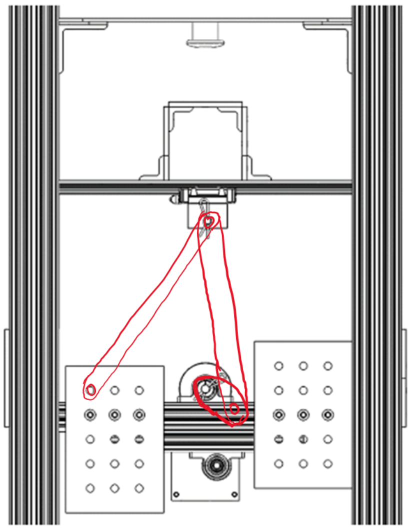
Since our previous design successfully pushed the button, our main focus is to reduce the mass of the system to increase our button push time to mass ratio. This decision is also driven by the fact that we had one of the largest masses of the class.



This design will keep the same length of each link but decrease the width of all three links to one uniform width to reduce total mass to below 100g



This design will have the same width for the rocker and coupler and a slightly larger width for the crank. The overall mass should be below 70g for this design.



This design will have a tiered width system where the relative widths are rocker<coupler<crank. The overall mass of this system is estimated at less than 80g.

The design that we have chosen to continue with is the second one shown above. This design will compensate for the crank having more complicated loading than the rest of the links while still providing a substantial enough width for both the coupler and rocker to support the anticipated load along with extra load due to imperfections in the real machine and set up. The design will also feature fillet corners on the hex hole in the crank to reduce the point loads on each wall.

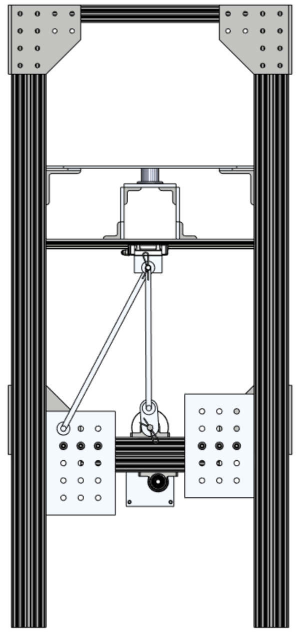
Iterative Stress Analysis

Our orientations of interest did not change from initial testing, as we viewed these orientations to still be most valuable to analyze. The three orientations chosen and the corresponding hand calculations for the chosen orientation are shown below. The first orientation shown was identified because this is the instance where the plate height is maximized, resulting in the greatest applied force on the linkage system due to the springs being compressed the most. The second orientation shown was identified because this would be the point where the motor would be causing significant bending stress on the crank and the coupler would be most susceptible to buckling. The third orientation was identified because this position shows where the crank would be most susceptible to buckling as it is completely vertical. Altogether, the first orientation was chosen to conduct stress analysis as we expected this position to be where the system would be under the most stress.

Though our hand calculations showed this was still a slightly conservative choice, we chose to use quarter inch thick acrylic with a width of .6 inches for the rocker and coupler, and a width of 1 inch for the crank. We wanted to ensure a successful improvement from initial to final testing, so we utilized a conservative factor of safety because our calculations did not account for the weight of the links, contact stresses, dynamic loading, or friction in the plate slider that would cause an increased external force on the system. . Our hand calculations are shown below:

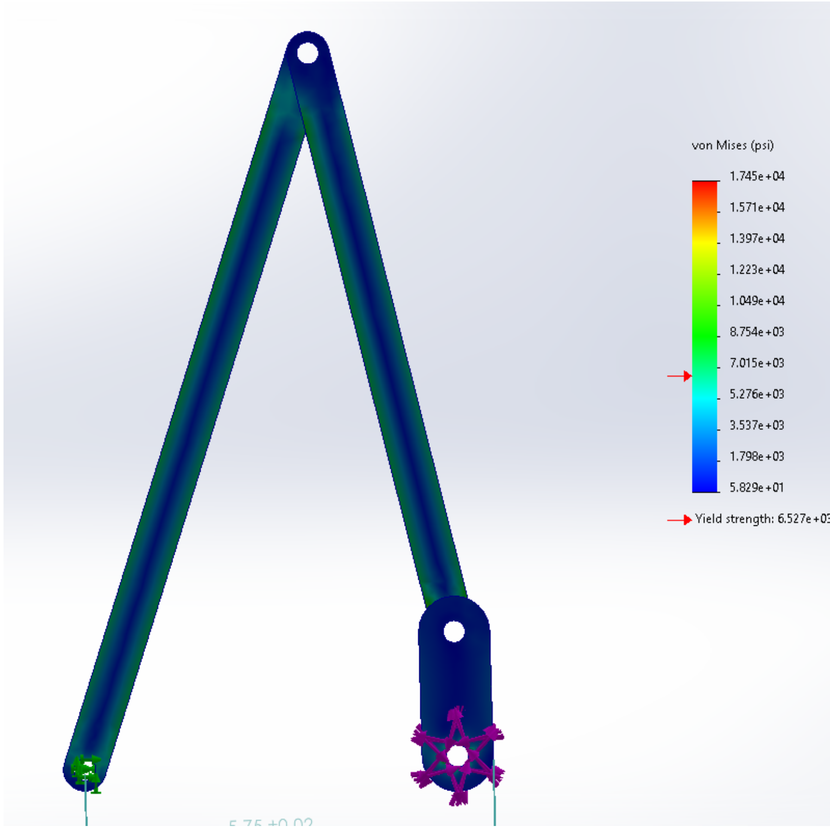
Iterative FEA Simulation

We opted to select the orientation that was most likely to cause failure in our linkage system for the FEA simulation. Specifically, we identified this orientation as when the linkage system was at its maximum height, as depicted below.

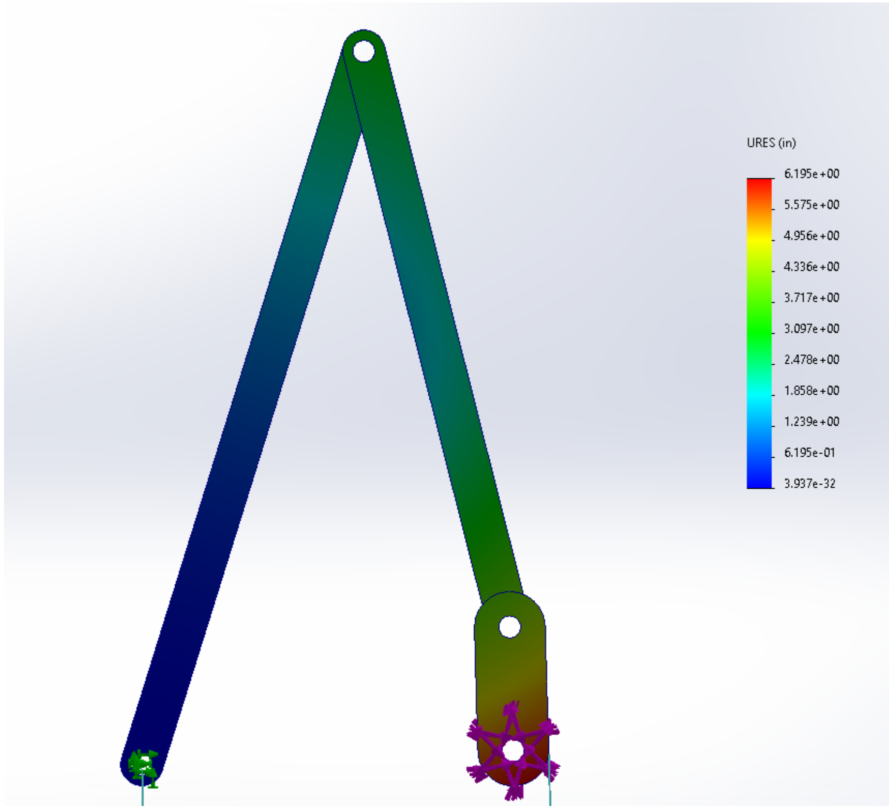


Orientation in Which the Linkage System Would Fail

This orientation is the same orientation that we used for our initial FEA simulation. Once again, this orientation was selected because the links would encounter the highest stress, arising from both buckling and axial stresses. Additionally, these stresses would be at their peak in this particular orientation. The FEA analysis is presented below, show casing the concentration of stress and displacement of the system.



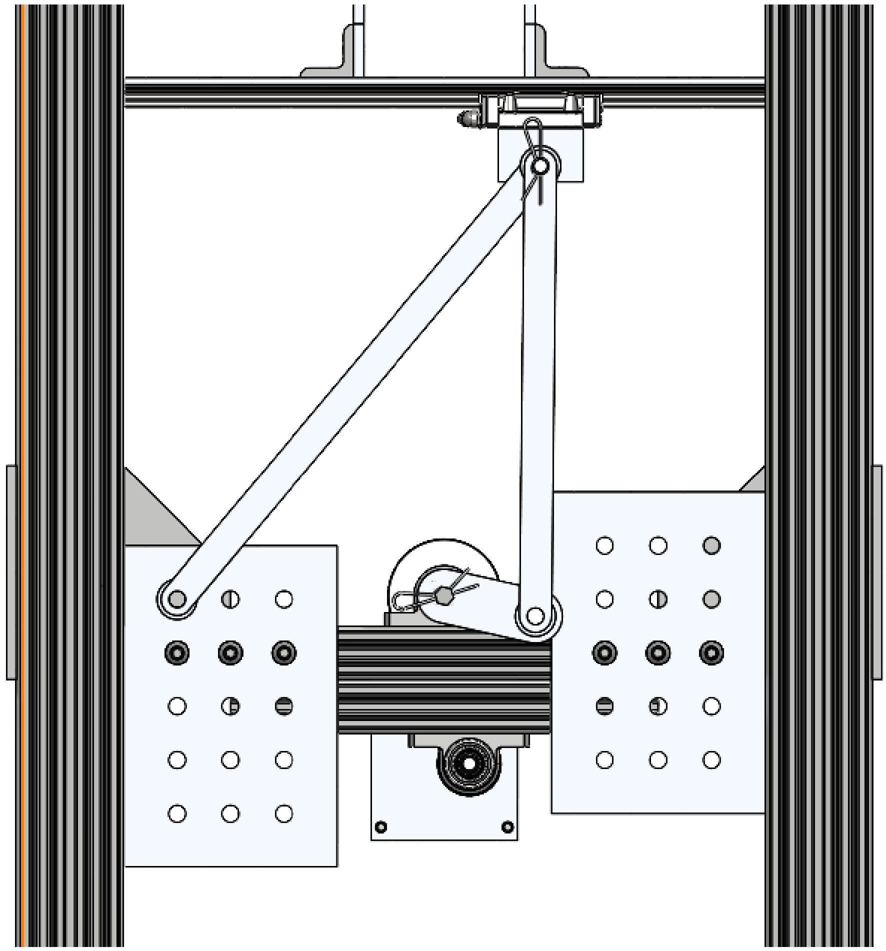
FEA Stress Analysis



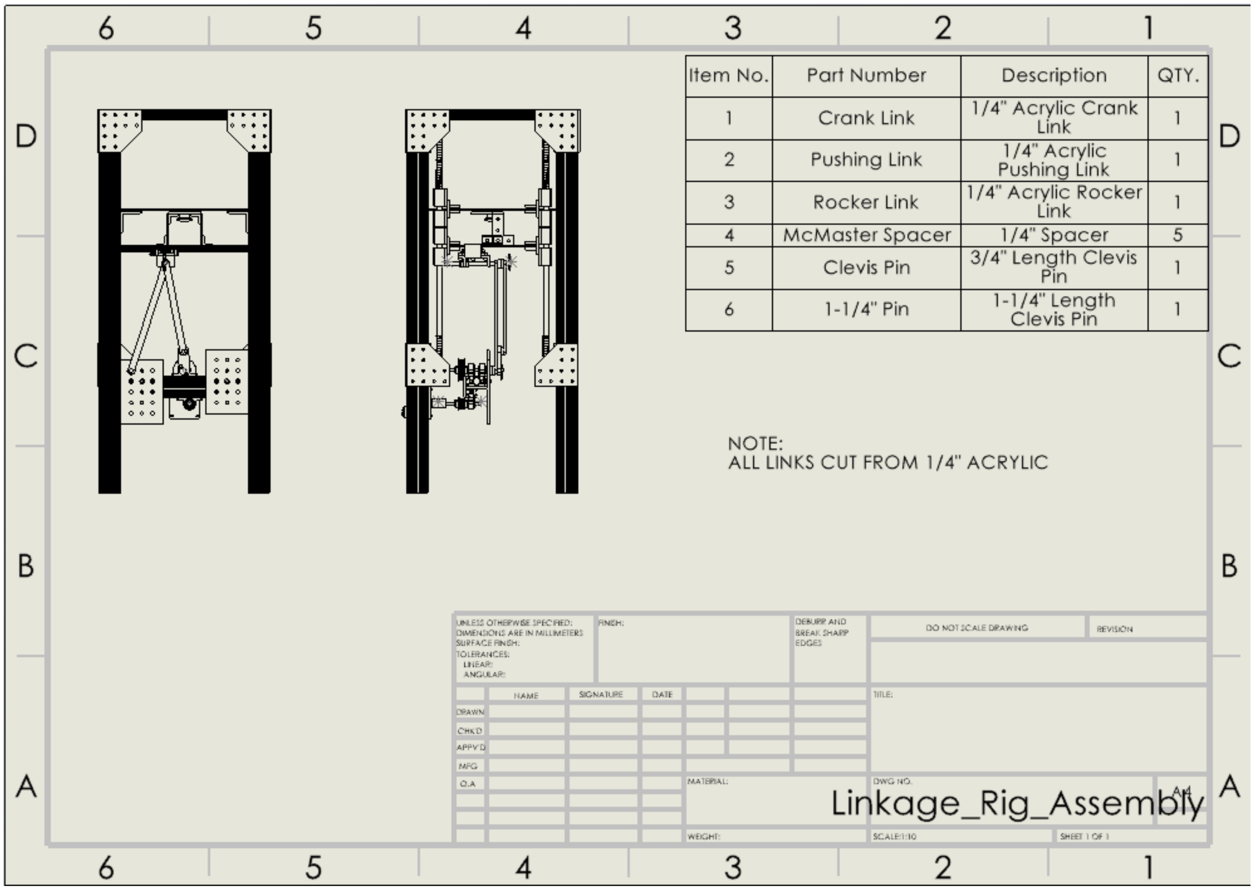
FEA Displacement Analysis

From the FEA Analysis, it can be seen there are non-negligble stress concentrations along the linkages specifically at the edges. This could be due to the fact that we reduced the overall width of our linkages, resulting in greater axial and buckling stresses throughout the linkages. Furthermore, are high stress concentrations at the pin connections, with the hexagonal pin still being the highest. However, compared to our previous design the filleting had reduced some of the stress concentrations within the pin. Overall, this result is very much in line with our stress analysis calculations which predict the linkage system to have a factor of safety of about 4. The linkage system, when compared to the initial testing, does displace way more. This is ,once again, due to the fact that we reduced the size of our linkages. There is also a greater amount of out of plane bending about the hexagonal cut when compared to the initial testing. These increased stress and displacements are accounted for in our stress-analysis calculations, where we do predict a larger amount of displacement due to the increased buckling stresses. Lastly, from the assembly, we estimated that the button would be pushed for about 25% of the time. This translates to about 30 seconds of total button push time.

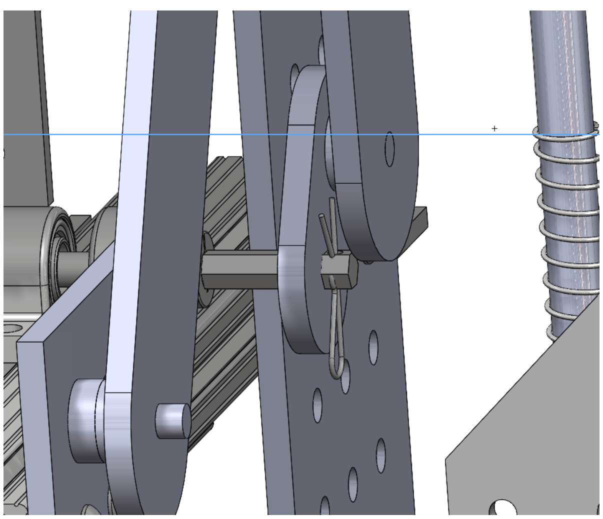
Fab and Asm Test Day

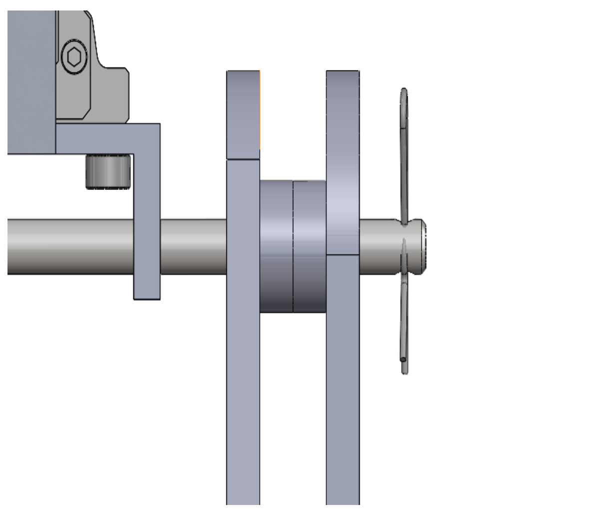


Final Linkage system in ideal starting position



Item No.	Part Number	Description	QTY.
1	Crank Link	1/4" Acrylic Crank Link	1
2	Pushing Link	1/4" Acrylic Pushing Link	1
3	Rocker Link	1/4" Acrylic Rocker Link	1
4	McMaster Spacer	1/4" Spacer	5
5	Clevis Pin	3/4" Length Clevis Pin	1
6	1-1/4" Pin	1-1/4" Length Clevis Pin	1


Bottom of System


Top of System

Assembly:

1. Attach crank shaft to crank link
2. Place 1-¼" Pin on peg board in the position specified in the drawing, than place two ¼" washers on pin

3. Attach rocker link to the peg board pin and the platform pin
4. Place two ¼" washers on the platform pin in front of the rocker link
5. Attach ¾" pin to free end of the crank link and place one ¼" washer on the pin
6. Attach the coupler link to the crank pin and platform pin

Final DXF

Test Day Results

On testing day, our system succeeded again. This was expected, as the same design had also performed well in the ungraded intermediate testing. Instead of altering the geometry of the linkage system itself, our group instead opted to reduce the weight of the links significantly in the time since initial testing. The system time was slightly lower than initial and intermediate testing, as one of the links was attached to an incorrect mounting point on the board, but the linkages still stayed within the bounds of the testing setup and did not break. The weight was significantly reduced at less than ⅓ of the initial. The system met expectations.

Continuous Improvement

There are a few things that we think should be kept the same about this project moving forward. First and foremost, we believe the intermediate testing day was an extremely valuable opportunity to optimize the linkage system without penalty. The intermediate testing day should definitely be kept as a component of this project because we think it ultimately improves the final results of the class for this project. For groups that failed initial testing, it allows those groups to secure a design that they can count on for final testing day. Additionally, for groups that passed initial testing, it allows them to be more risky in pursuing a fully optimized design. In the real world, products receive prototype testing, so this intermediate testing day imitates real world design. Second, we think the project description should remain as one long, well-organized document. The ability to read through a long description and decipher what information is particularly useful such as constraints, deadlines, etc. is incredibly valuable to engineers in the real world and we think that the format of presenting the project description should remain. Third and lastly, we think the presentation aspect of this project should remain. We think it is helpful to practice public speaking about engineering concepts while also learning useful ways to present information in the form of graphics and tables.

In terms of minor adjustments to the project, we believe that for the initial testing, the Fabrication and Assembly submission should not be due until the night before initial testing. This allows groups more time to conduct stress-analysis and further analyze their linkage system, instead of just geometrically creating a design that fits the constraints and then conducting stress analysis on that design afterwards. Also, we believe that the group size per team should be increased from three to four members for all teams. Our group utilized four members, and we found that number of team members especially useful in attacking the project and collaborating based on members' strengths and weaknesses.

For major adjustments to the project, we believe that there are two main adjustments that can be made to improve the project. First, we believe that material selection should be a more important factor in this project. For all groups it became obvious pretty quickly that plywood was not the best choice, and all groups utilized the acrylic. We believe that more material options, in the range of five to eight materials, would allow for a much more intensive material selection process and allow for more unique designs. The differences in material could be in the form of thickness or type of material, but either way it would allow for more thought in material selection, which replicates the real-world design process further. Another major adjustment to the project that would be beneficial is for students to determine the geometric constraints themselves. Instead of providing the diagram with the dimensions between connection points on the testing rig, students could measure these dimensions themselves. This would require teams to go to TechSpark and analyze the testing rig prior to initial testing day. Although measuring dimensions seems like a relatively simple task, it allows students to be a bit more hands-on and determine what measurements are necessary. It also requires students to learn how to measure different dimensions, such as hole diameters, hexagonal diameters, and distances between connection points if they are not familiar with how to do so.

To create a different design challenge, our group thinks it would be pretty neat to include a wide button below the motor that the crank can graze over that allows for additional time to be added to each team's score. A diagram of this button is shown below. The use of this additional button would be to incentivize teams to make their cranks longer, so that less teams simply design very wide and short crank links. Similar to how the coupler and rocker have a 2:1 length to width ratio, the crank could also have a ratio applied to it. This would make simple adjustments like filleting the hexagonal corners much more valuable to a thinner crank. We believe our current design with a slightly extended crank length would double our button press time. This change to the project would allow for more constraints in the project, and allow groups to focus on the upwards arc and downwards arc of their linkage system. The design of this new challenge is shown below.