Tiny Transforming Table (T^3)

University of California, Berkeley
ME 130
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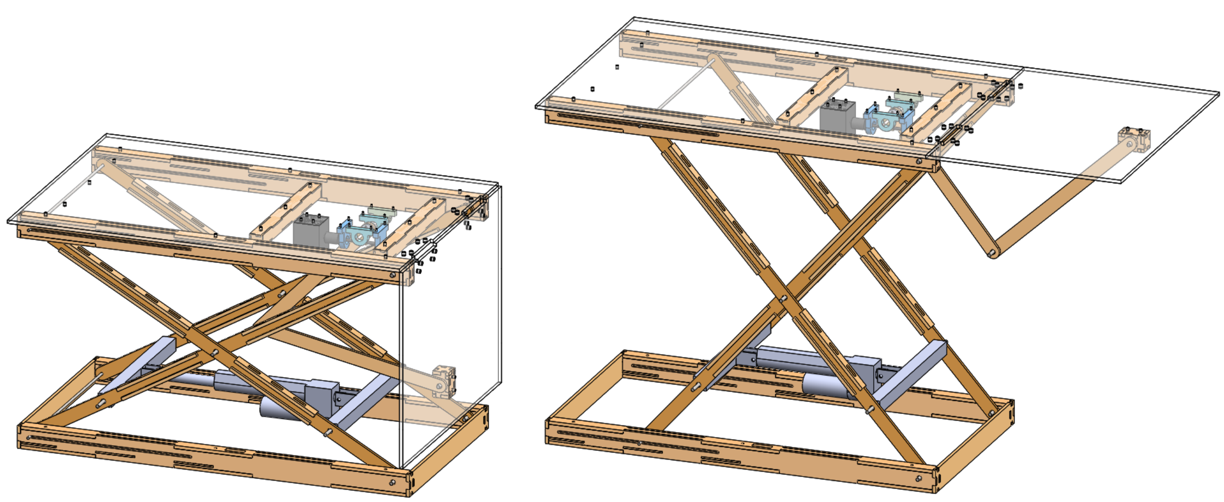

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1. Background

As housing becomes increasingly unaffordable in many metropolitan areas across the United States, some people are foregoing typical accommodation options for a more economical and unique type of home. These off-the-grid dwellings frequently referred to as 'Tiny Houses', are popular among Millenials, and have exploded in the past decade, with sales increasing by 67% in 2017 alone. It is easy to see why this might be: with an average cost of $119,000 for a tiny home with a foundation, and a mere $46,300 for one on wheels, 68% of tiny homeowners don't have a mortgage [1]. In comparison to a median home listing price of $1.3 million in San Francisco [2] and $939,000 in Greater Los Angeles [3], this is an absolute steal that still allows it's occupant to reside in a high-value property region with the security of homeownership.

A home is considered to be a tiny home if it is under 400 square feet [4]. Living with such limited square footage for a bedroom, living room, bathroom and kitchen produce a need for ultra-efficient usage of space. The square footage restriction means that one does not have the luxury to purchase and keep a separate dining table, coffee table, and work table or desk. In such homes, transforming furniture allows people to have all the pieces of furniture they desire. Many people have to compromise having a workspace or dining area for the comfort of a larger kitchen or to include a couch that can seat more than one person Something that takes up large amounts of space is tables Whether that table is a coffee table, dining table, or desk, the area of floor space that it covers is pretty substantial As a result, many people will compromise one type of table for the table that they find more use for them. Other people, however, have found ways to incorporate a table into a different piece of furniture that can transform between the two pieces as needed. For instance, some people have tables that fold up, and the bottom of the table has a painting of some sort on it that serves as decoration when the table is not being used Another example of transforming furniture is the transformation of a table from the height of a coffee table to the height of a desk or dining table This allows for a common space to change from a living area to a workspace or dining area. However, the process of lifting the tabletop from one height to another can be strenuous and requires strength that not everyone has.

Our project, the Tiny Transforming Table looks to address the need for multipurpose furniture in such Tiny Homes by functioning as a Coffee Table, a Desk and a Dining Table based on the user's requirement of it and motorizes its transformation so that all kinds of people can use it.

2. Functional Engineering Specifications

Specifications:

1. Original tabletop dimensions - 20” x 30”
2. Expanded tabletop dimensions - 20” x 45”
3. Table initial height - 18”
4. Table max height - 26” [1]
5. Table lifting / lowering speed - 1”/second
6. Tabling expanding time - 10 seconds

Explanations:

1. That is the average dimensions of a common coffee table
2. That is the average dimensions of a common desk and can also be used as a dining table
3. That is the average height of a coffee table
4. That is the average height of a desk or a dining table
5. Low speed is required so that objects left on the table do not fall or spill while lifting or lowering the table
6. The table should expand fairly slowly so as to not have any jerking motions that impact the mechanism

Functions / Goals:

1. Raise the table from a height of a coffee table to that of a desk or dining table
2. Expand the table to provide more surface area
3. Keep the weight of the mechanism to less than 15 lbs so that it does not add too much weight to the table.

[1] Originally intended to be 30”, but had to be reduced when the linear actuator was interchanged for a stronger one.

3. Conceptual Design and Freehand Sketches

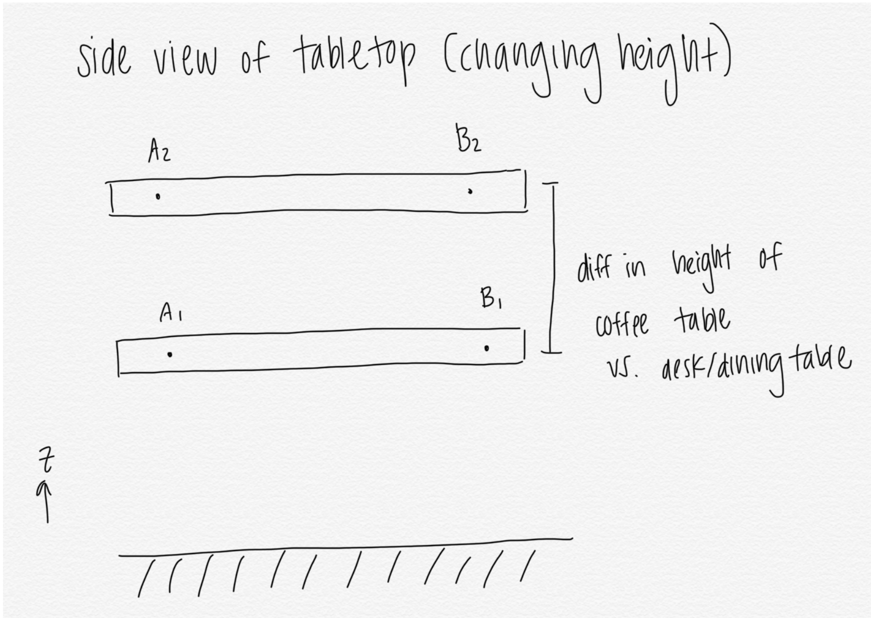


Fig 1. Concept View (Side View of Table)

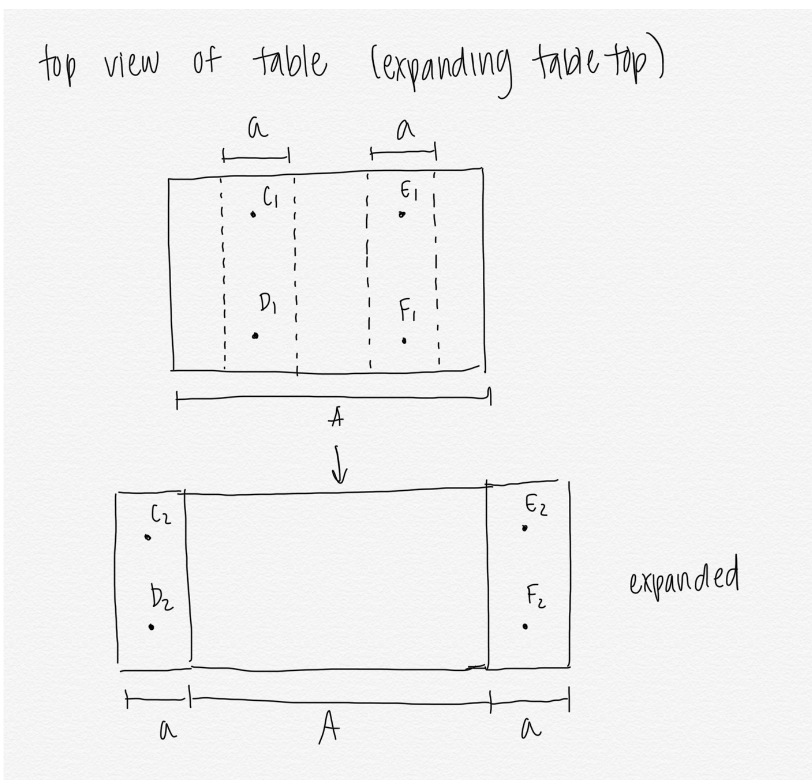


Fig 2. Concept View (Top View of Table)

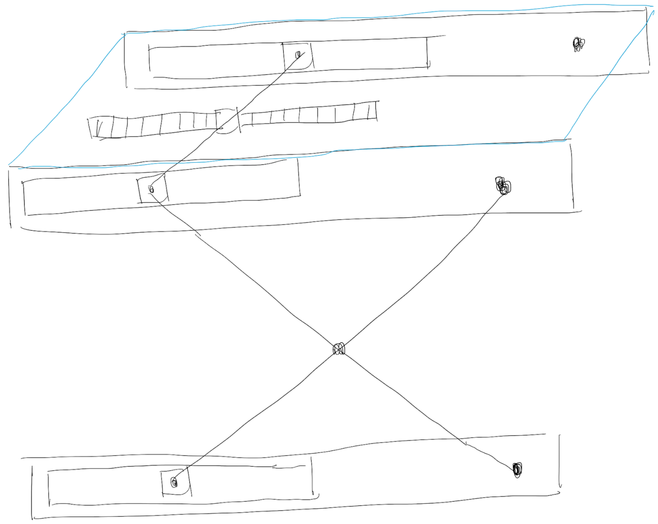


Fig 3. Linear actuator mounted to tabletop

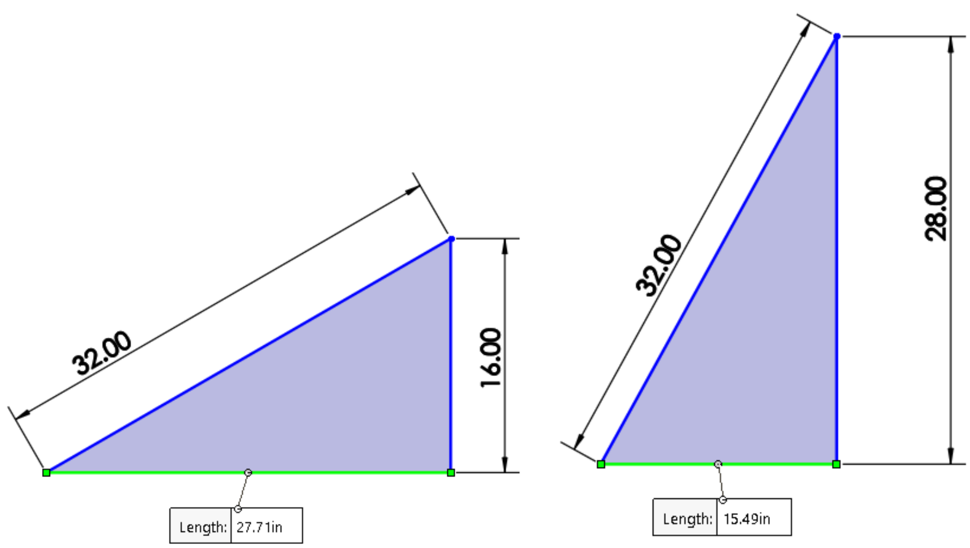


Fig 4. Determining slider travel

Length of the link must be longer than the dimension of the table (30" wide): 32"
Min height - 2*distance to center of link for slider (1") = 16"
Max height - 2*distance to center of link for slider (2") = 28"
Total travel of slider = 27.71" - 15.49" = 12.22"

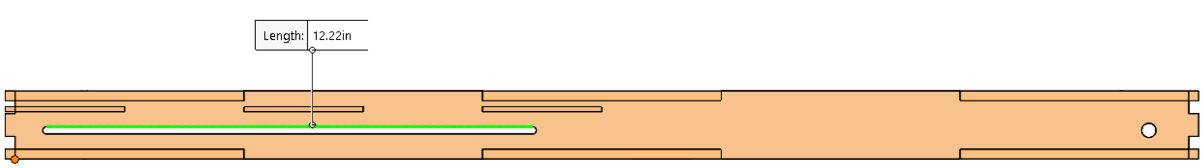


Fig 5. Slot for slider in the link attached to table/ground

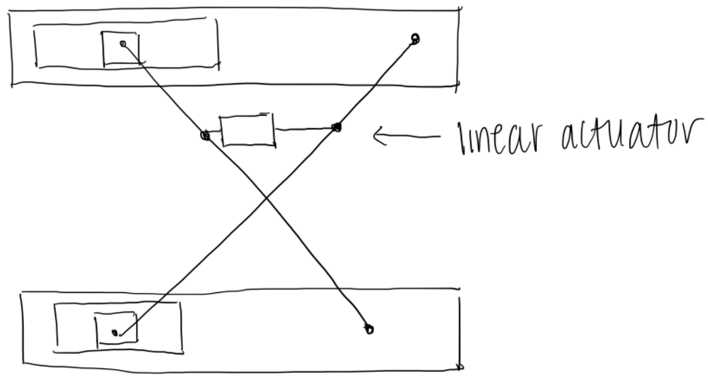


Fig 6. Linear actuator mounted on links because of limited travel

Total travel of initial linear actuator: 300 mm = 11.81” < slider travel

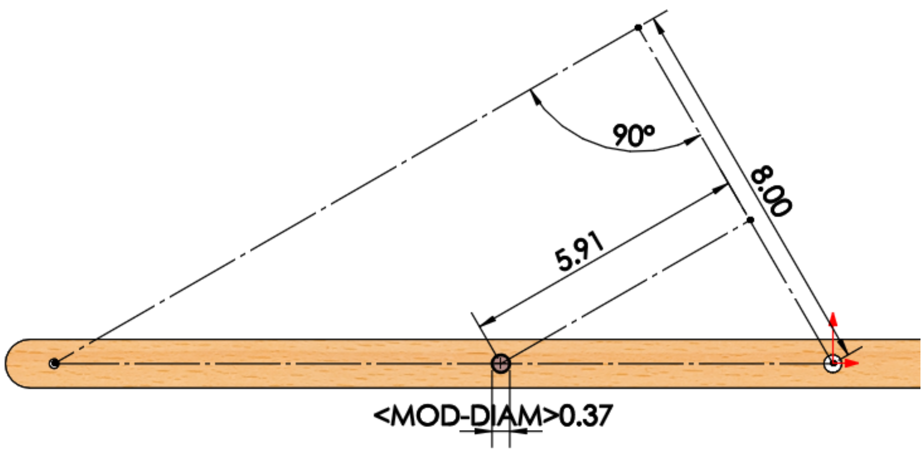


Fig 7. Determining placement of linear actuator on cross link

5.91” = 150 mm (half of the linear actuator stroke)
8” = ½ min table height - 2” (center of the link)

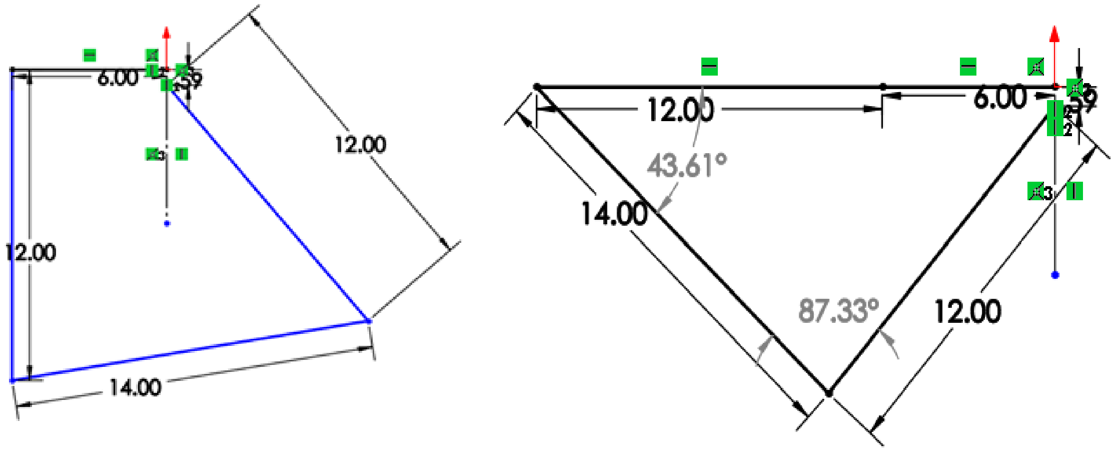


Fig 8. Initial and final positions of expansion mechanism.

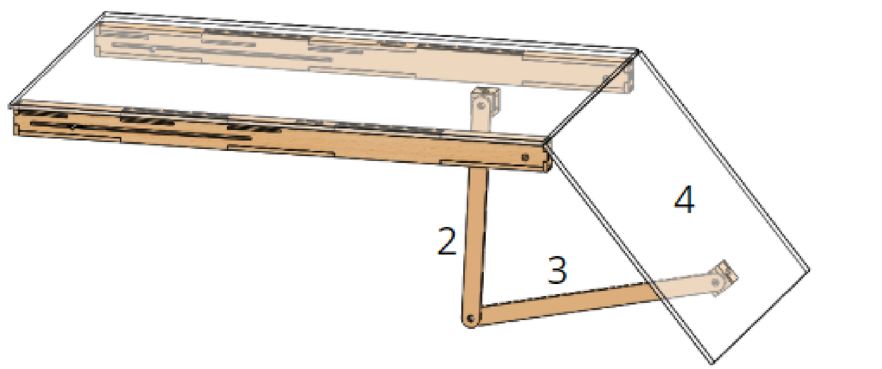


Fig 9. Expansion links numbered, tabletop is ground.

Table expansion was achieved through the design of a four-bar mechanism; the desired output is completed by link 4 in order to guarantee alignment with the rest of the table. The mechanism is a double crank (P + Q > S + L, with ground as the shortest link), but the motor only rotates link 2 back and forth through ~81.5 degrees at a constant velocity, which results in link 4 rotating 90 degrees between extreme positions. As labeled in the figure, the transmission angle is 43.61 degrees which is greater than the minimum suggested 40 degrees to prevent locking. The 87.33 degree angle formed between links 2 and 3 at full deployment is close to 90 degrees, minimizing out-of-component forces when maximum force is required. The 0.59” y-component of the ground link reflects the location of the drive motor in the assembly.

4. Detailed Design

The majority of the mechanism was laser cut from ¼” plywood. All the legs and links of the mechanism are made up of laser-cut plywood. The tabletop is made of acrylic so as to see the mechanisms that are housed below the top of the table. By using a scissor lift mechanism, we can ensure that the top of the table stays perfectly horizontal as the whole table rises and falls.

Because our project was a table, we ran a stress analysis using two different parameters. One with a normal load of 30 lbs to represent the weight of dishes and food being put on the table, and one modeling a person sitting on the table with a localized load of 150 lbs. We modeled the wood as balsa wood as there was no plywood material in the Solidworks library. As we can see from the following figures, even with a person sitting on the table, the displacement on most of the table is very nominal. The only part where there is high deflection is on the pin connectors, but that is also mitigated due to them being in slots. When looking at the stress due to the human sitting on the table, we can see that the stress does increase a bit, but it can still be disregarded as the stress recorded is still very low when compared to the yield strength of the wood. As expected the stress is higher around the location where the person is sitting and that stress is also somewhat apparent on the legs of the table. Overall our table is able to withstand the loads it was meant to (the weight of food and normal dishes).

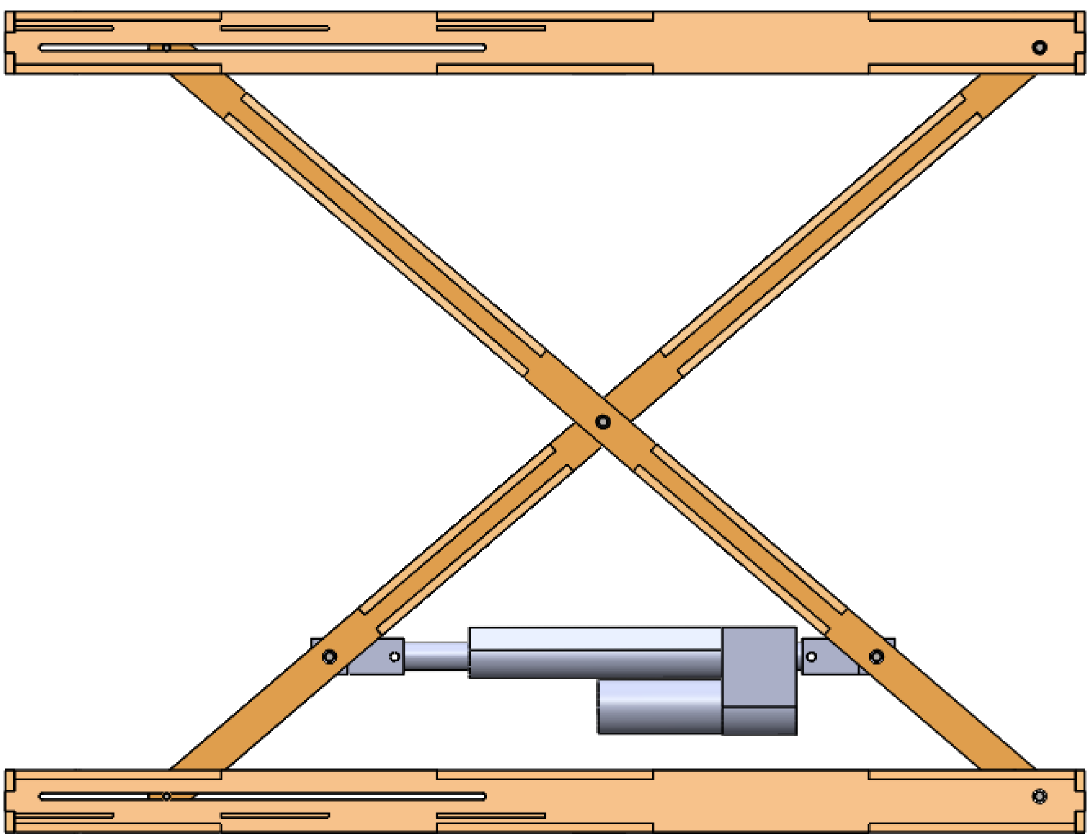


Fig 8. Lifting mechanism

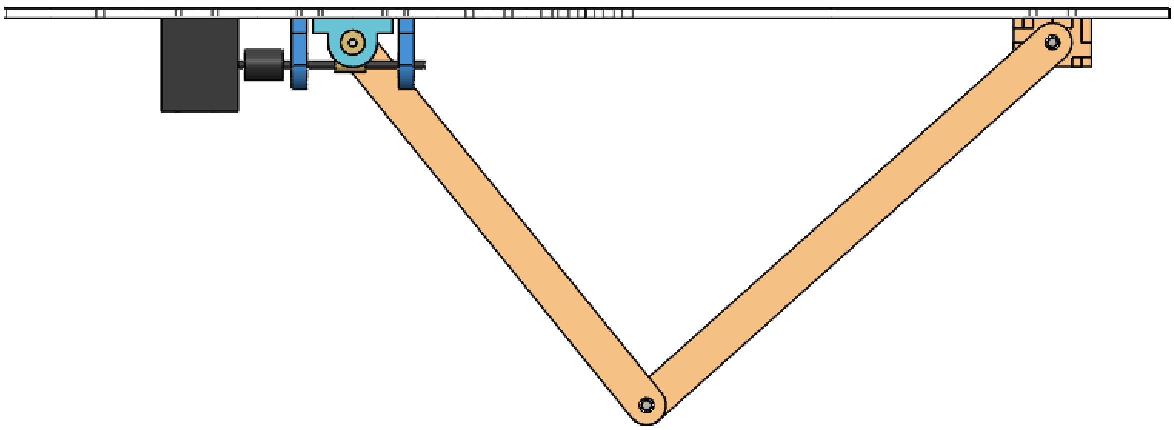


Fig 9. Expansion mechanism

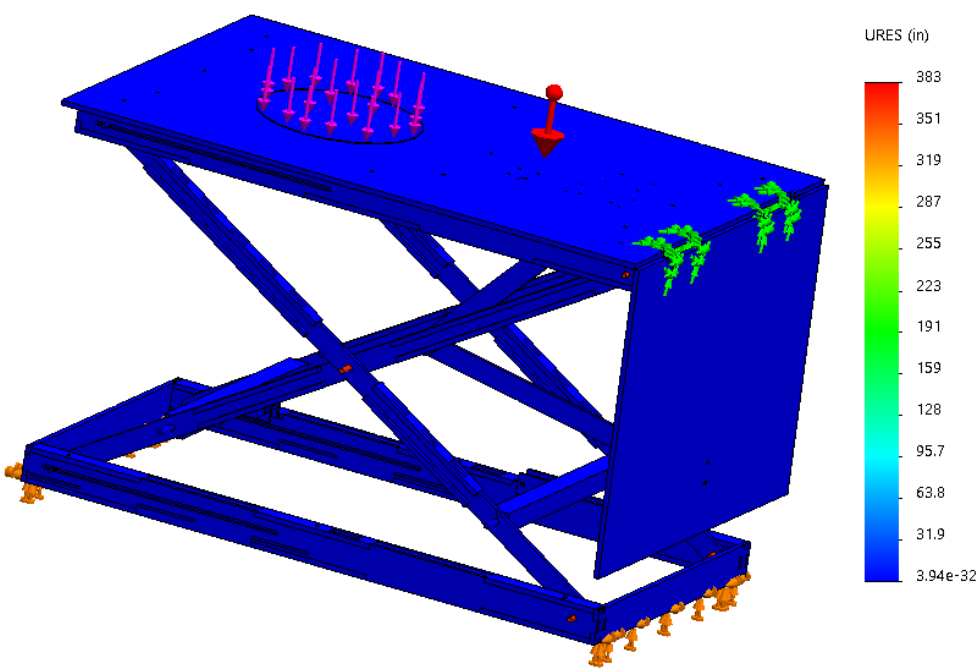


Fig 10. FEA for table - displacement with a person (150 lbs) sitting on the table

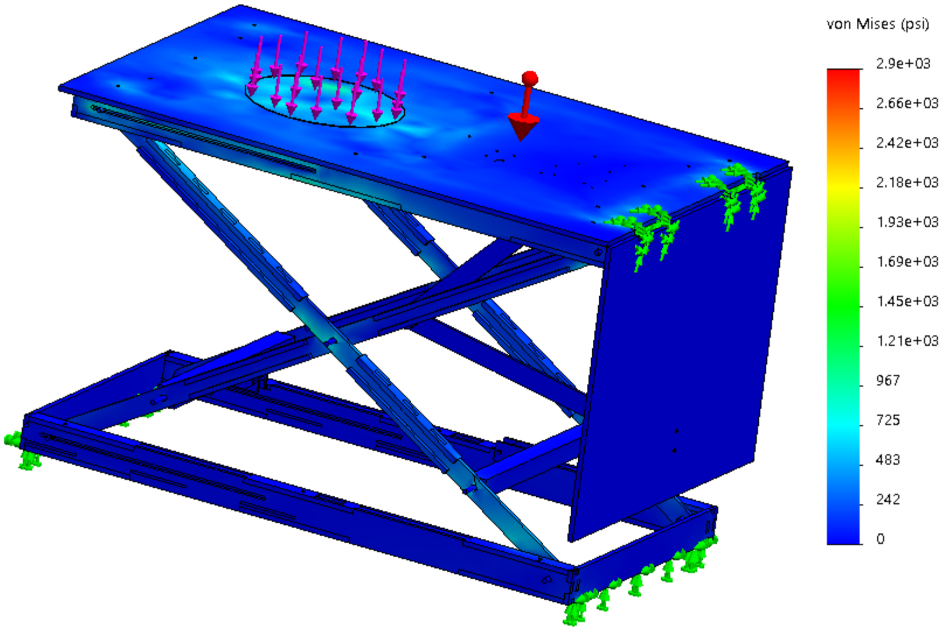


Fig 11. FEA for table - stress with a person (150 lbs) sitting on the table

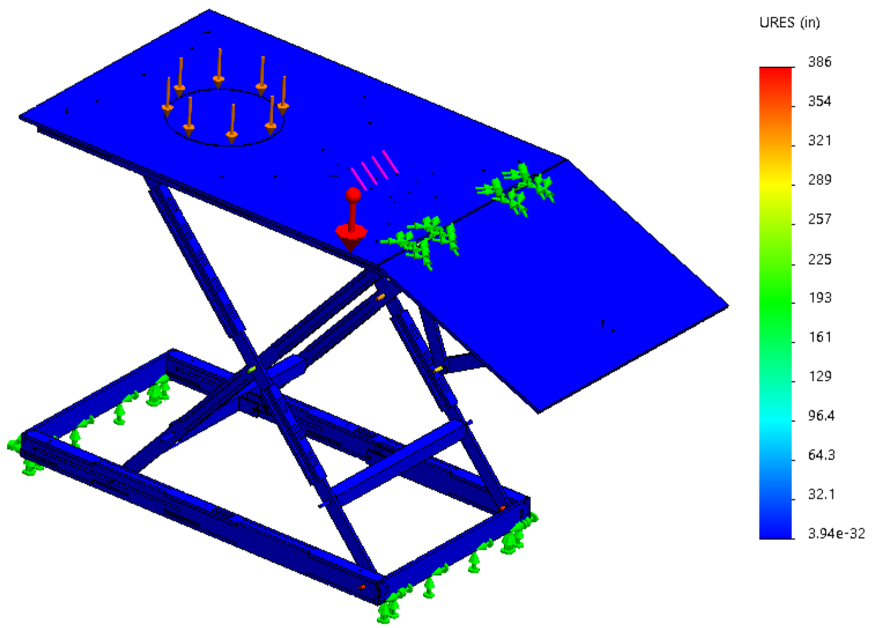


Fig 12. FEA for table - displacement with a person (150 lbs) sitting on the table

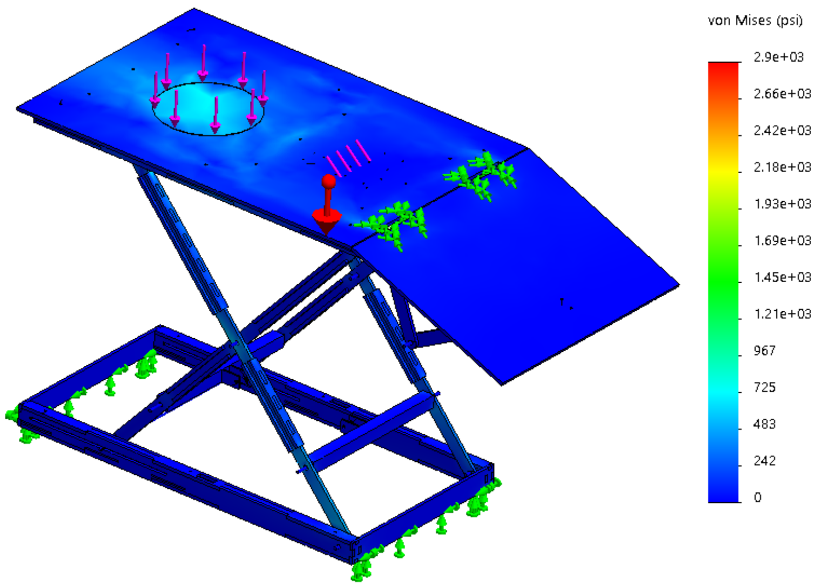


Fig 13. FEA for table - stress with a person (150 lbs) sitting on the table

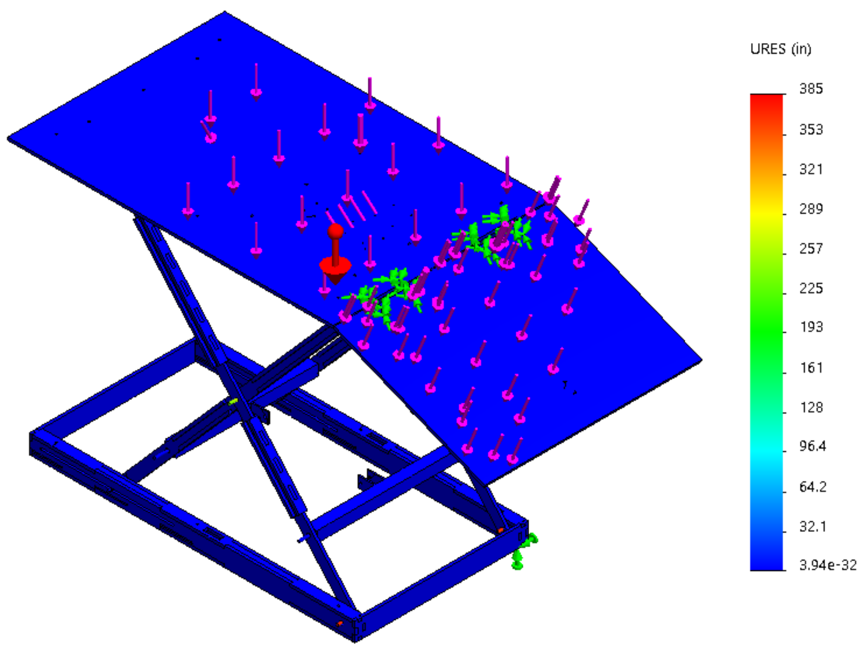


Fig 14. FEA for table - displacement with a normal load for dishes (30 lbs) sitting on the table

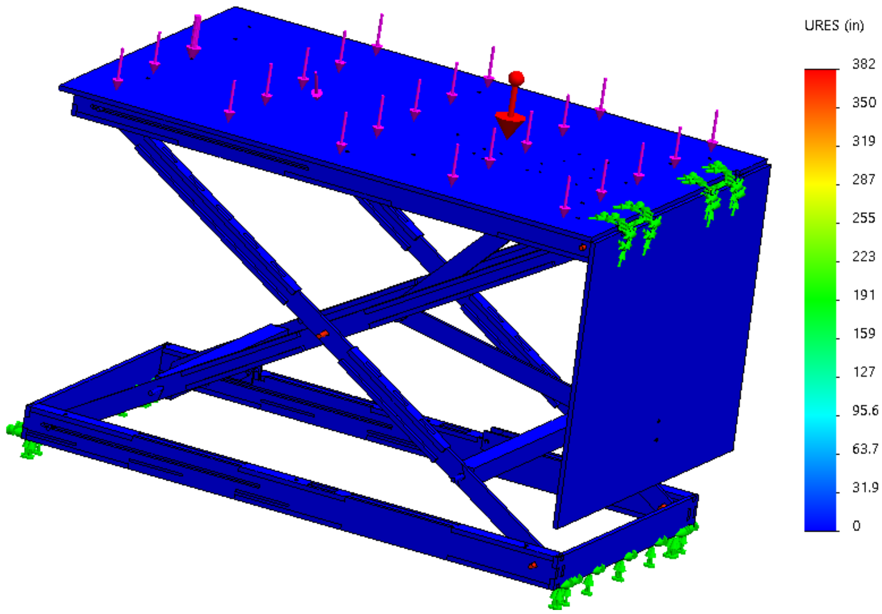


Fig 15. FEA for table - stress with a normal load for dishes (30 lbs) sitting on the table

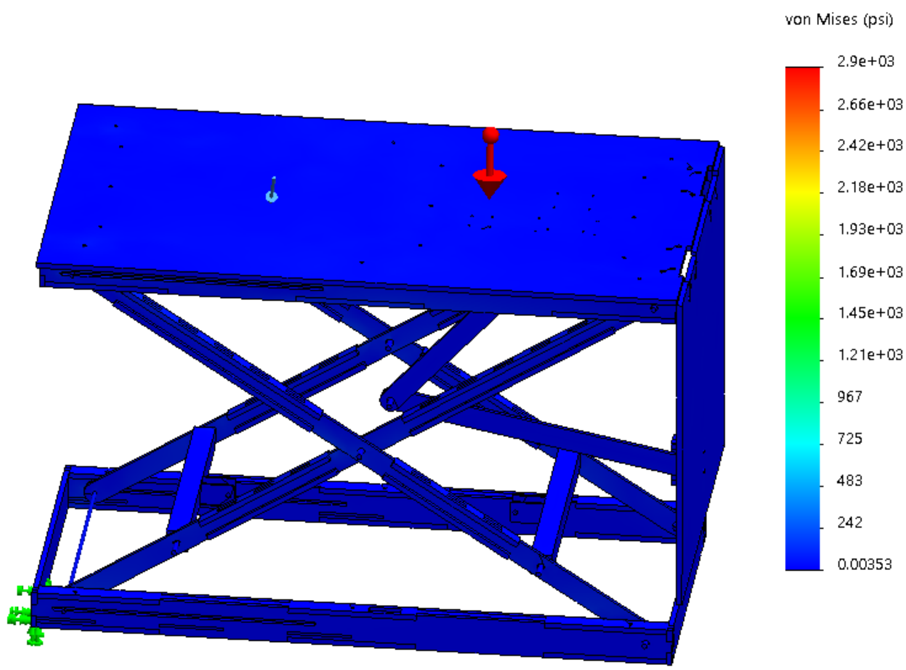


Fig 16. FEA for table - displacement with a normal load for dishes (30 lbs) sitting on the table

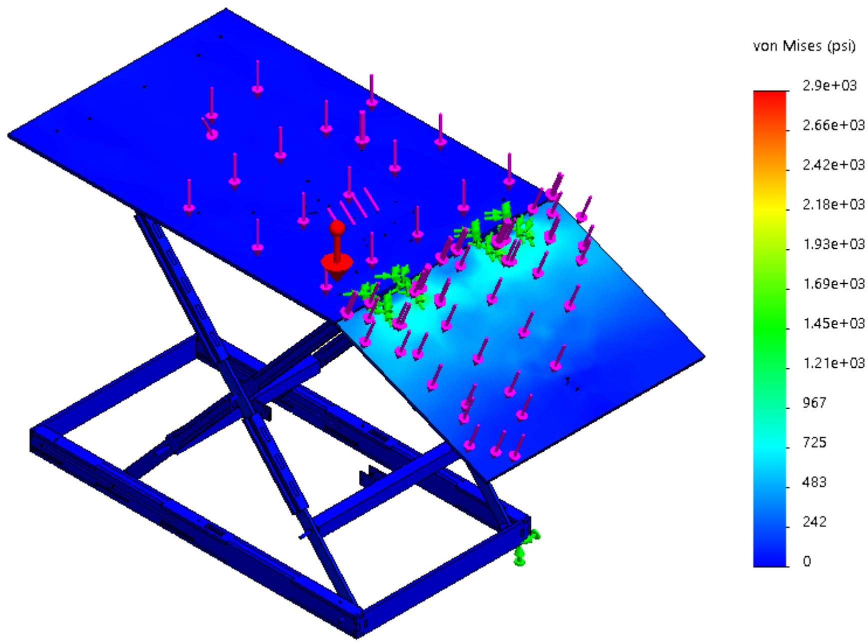


Fig 17. FEA for table - stress with a normal load for dishes (30 lbs) sitting on the table

We also conducted a motion analysis study to gather data on the relationship between drive and output velocity, as well as the required forces over the course of operation. Plots for the lifting mechanism were produced in Solidworks by implementing a linear motor at the actuator location, which moved 4 inches forward and back over 20 seconds at a constant speed (magnitude); similarly, plots for the expansion mechanism were produced by implementing a motor at link 2 that rotated ~81.5 degrees from the starting position and back over 12 seconds at a constant speed (magnitude). These conditions closely replicate those of the actual mechanism.

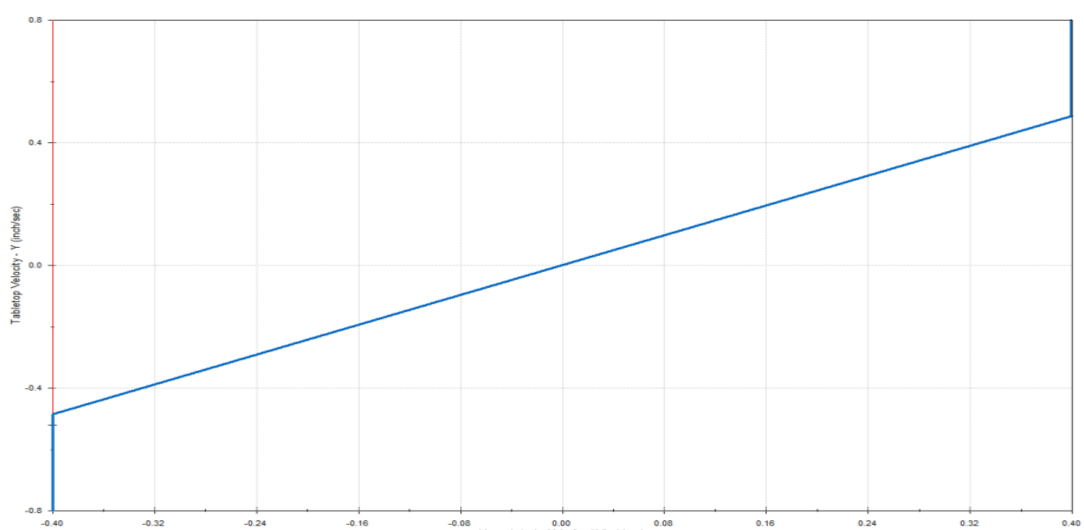


Fig 18. Tabletop Velocity Y vs. Linear Actuator Velocity in inches per second.

Looking at the velocity motion analysis for the expansion mechanism, it is shown that during operation the driver link angular velocity has a constant magnitude of 13.59 degrees per second, which corresponds to a constant tabletop angular velocity of 19 approximately degrees per second. Because of the geometry and constant driving speed, this linear relationship is to be expected. A similar linear relationship is observed between the linear velocity of the actuator (x-direction) and main tabletop (y-direction), with .4 inches/sec corresponding to the constant speed achieved by the actuator, and resulting in a rise speed of .8 inches/sec. It is worth noting that, because of last-minute issues, the table only rises about 8 inches instead of 12, and at this speed completes the cycle as expected.

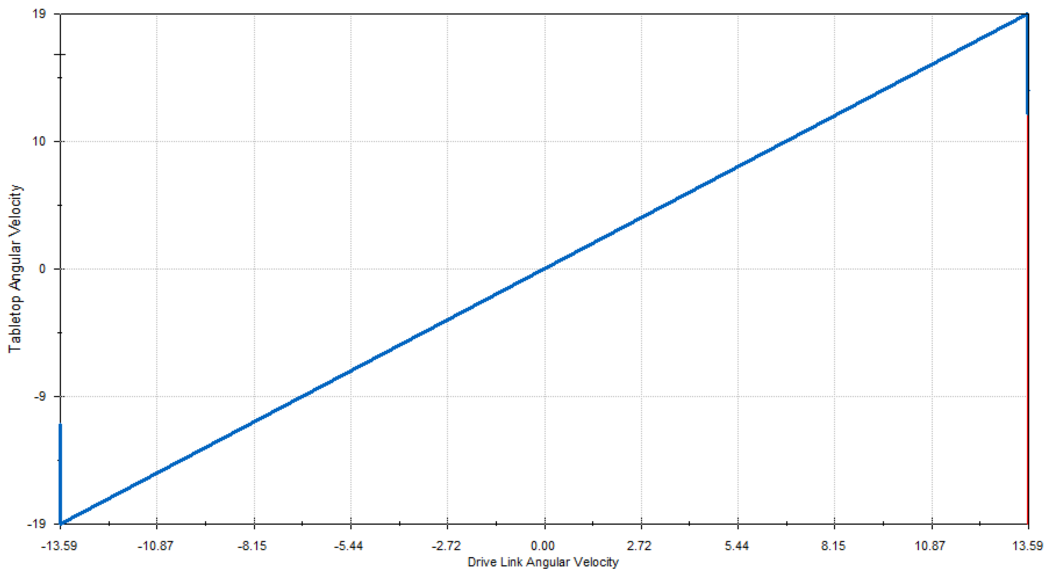


Fig 19. Tabletop Angular Velocity vs. Driver Link Angular Velocity in degrees/sec

Solidworks force analysis plots were created to determine the force requirements for the drive elements used in the velocity study above. The required motor torque for expansion is quite low, with a peak around .03 lb*in; the plot reaches a maximum at full deployment, which makes sense, as this is when the motor is taking the most of the expansion section's weight. On the other hand, the required linear actuator force reaches a minimum around 9 pounds at full deployment, and a maximum of about 16 pounds right as motion begins. This is also to be expected, as less force should be required as the links become more perpendicular with actuation direction.

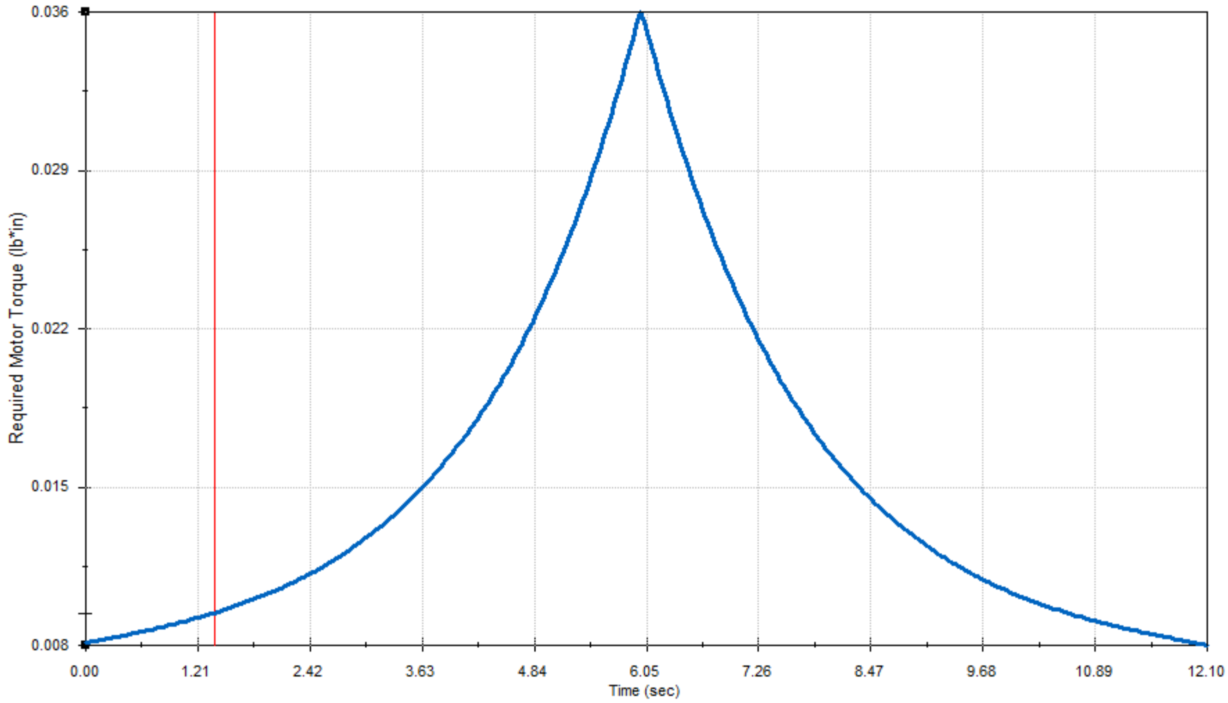


Fig 20. Required Motor Torque vs. Time

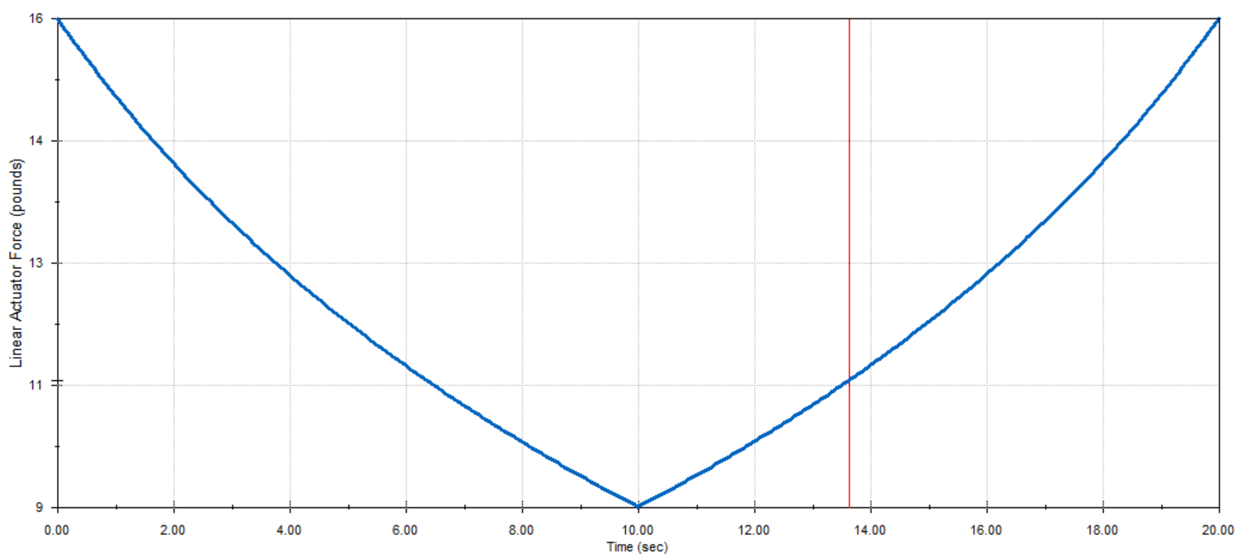


Fig 21. Linear Actuator Force vs. Time

Our original design called for two actuators, a linear servo and a stepper motor, controlled by two independent controllers, and coordinated by an Arduino (which also read user input). The relationship between these elements can be found below. The linear actuator controlled the scissor lift mechanism, while the stepper motor controlled the expansion mechanism through a worm gear drive, which prevents backdrivability. Each actuator is controlled via a dual throw switch, meaning the switch has three possible positions: forward, neutral, and reverse.

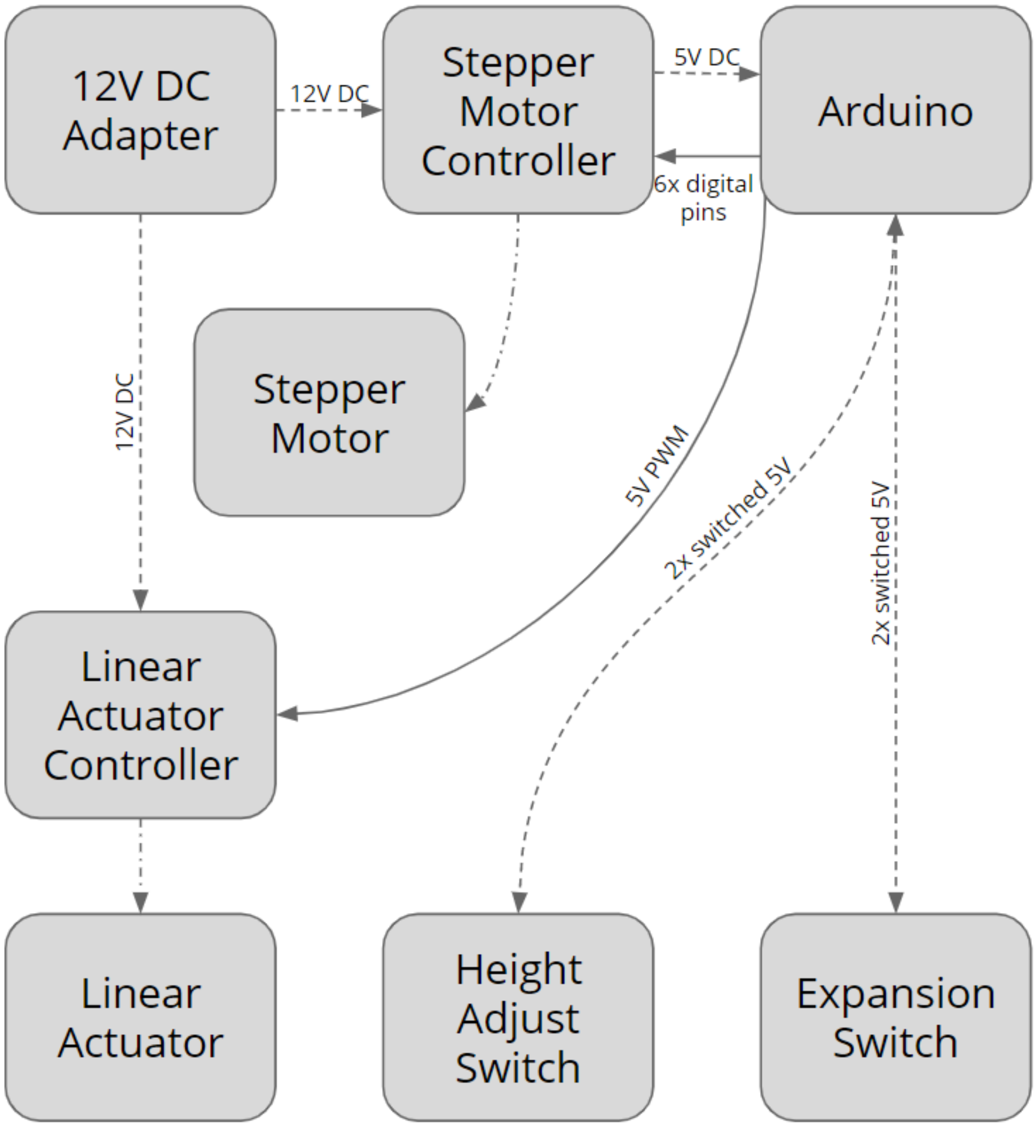


Fig 22. Original Electronics Block Diagram

5. 3D Drawings

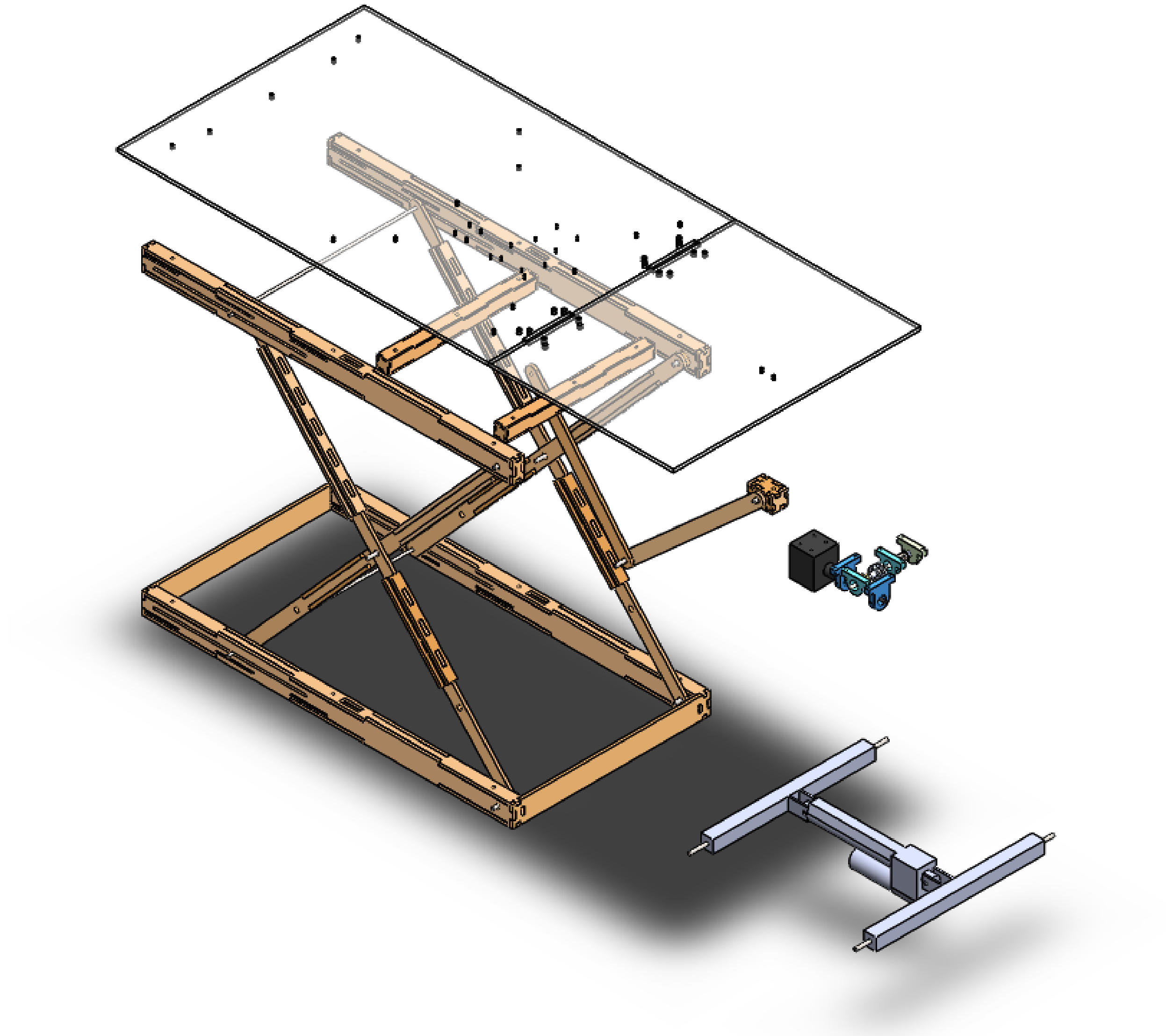


Fig 22. Exploded View

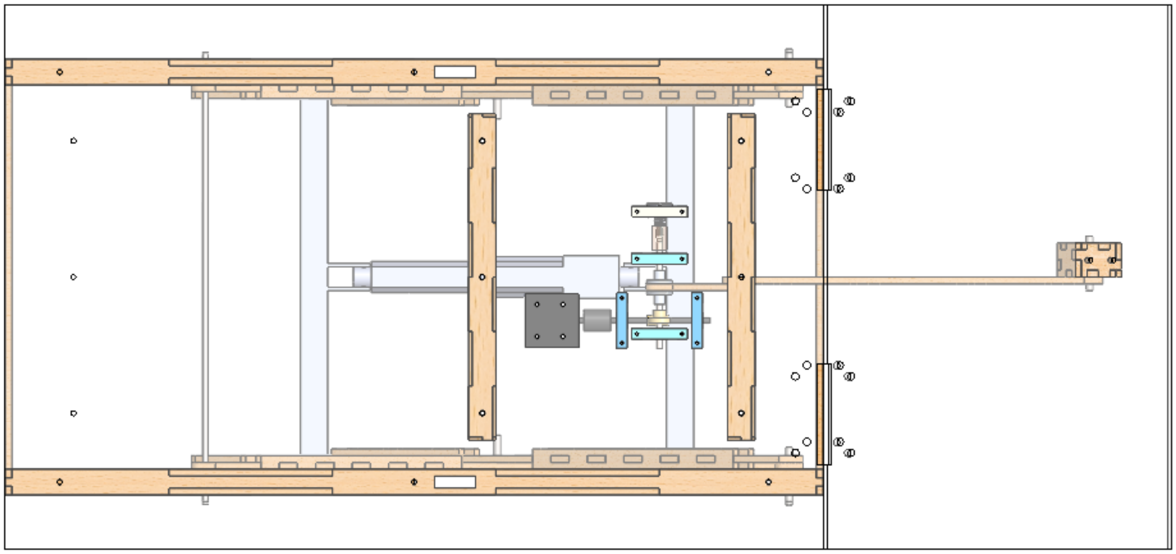


Fig 23. Top View

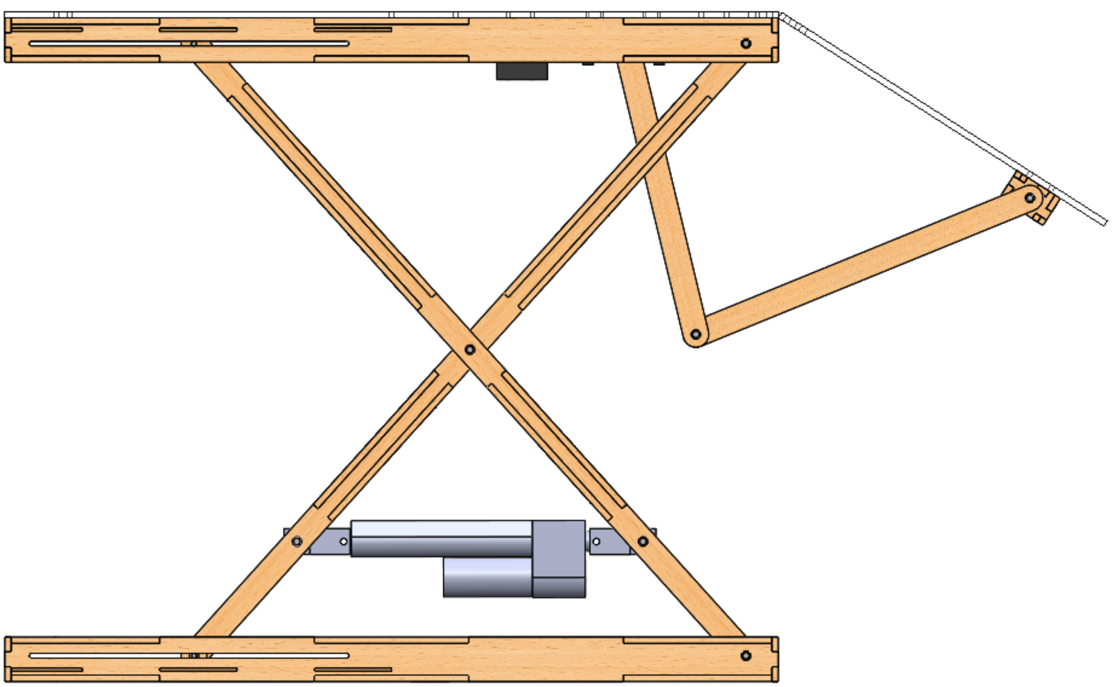


Fig 24. Front View

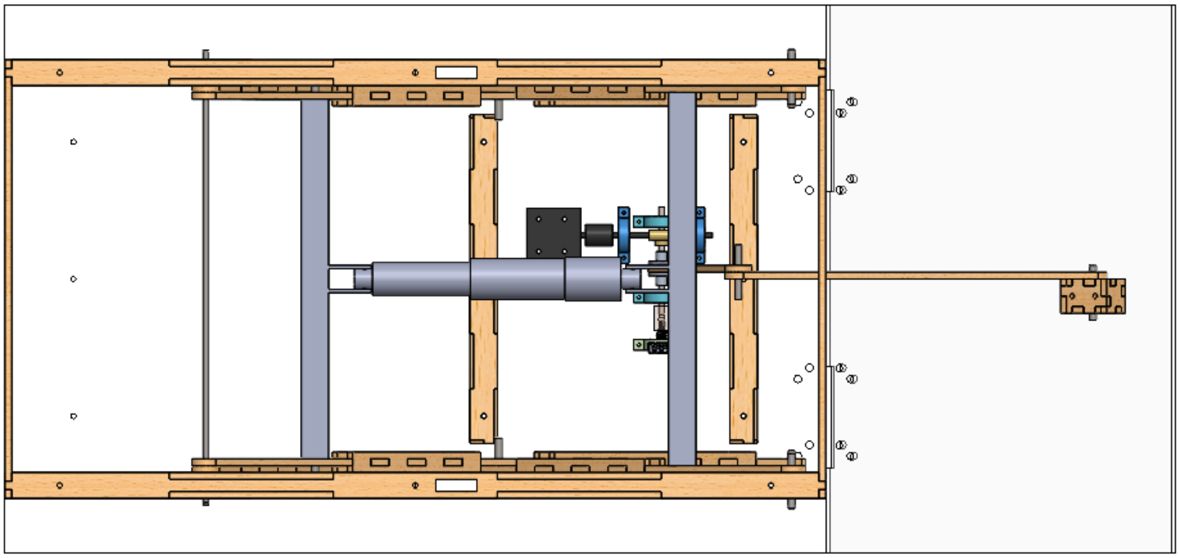


Fig 25. Bottom View

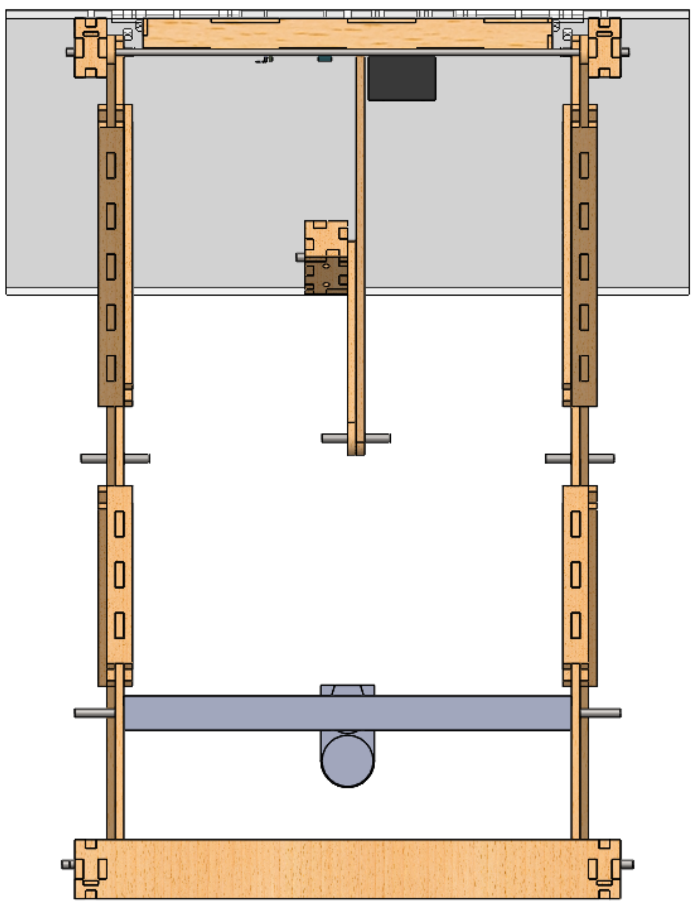


Fig 26. Left View

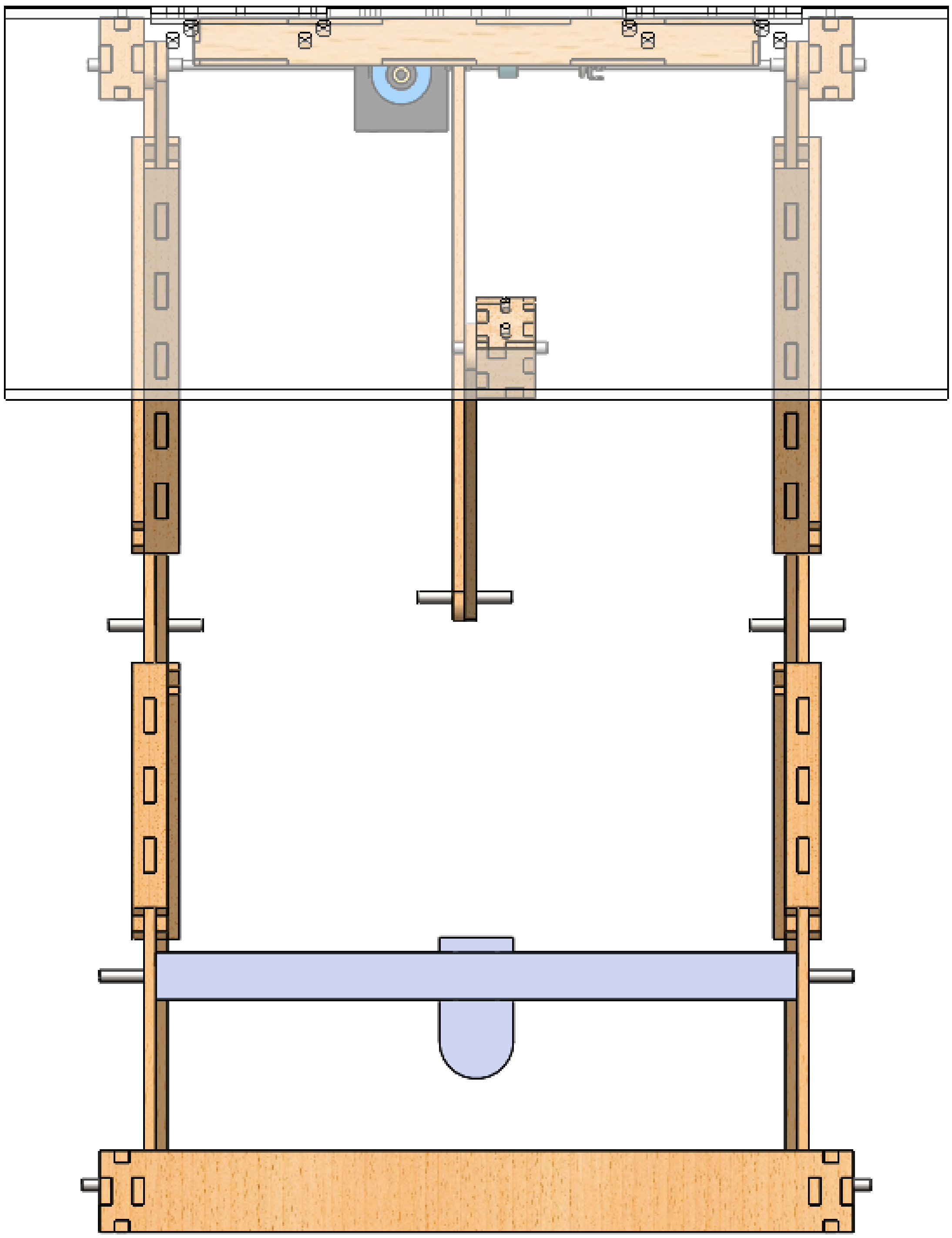
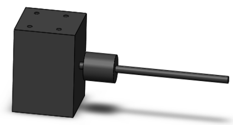
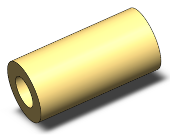
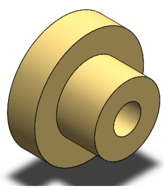
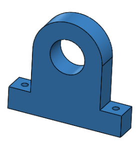
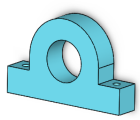
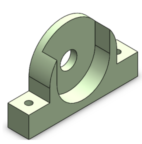
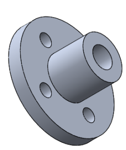
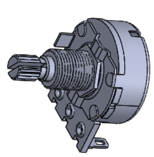
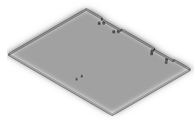
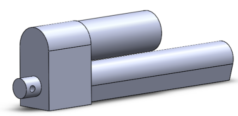
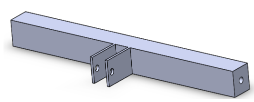
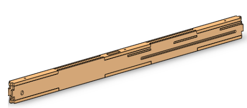
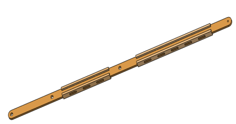
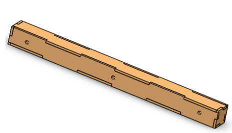


Fig 27. Right View

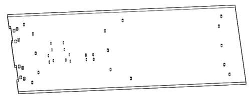
6. Parts List[2]

Part	CAD Representation	Quant.	Description
Motor and Shaft Coupling		1	• 12V DC gearmotor with 75:1 ratio to drive table expansion 4-bar • Flexible shaft coupling
Worm		1	• Provides additional 40:1 gear ratio
Worm gear		1	• Transmits motion from worm to drive link • Non-back drivable to prevent motor overload once deployed
Worm axle, gear axle, and potentiometer holders	  	5	• 3D printed to fasten to table and hold axles for the worm (taller) and worm gear (shorter) • 3D printed to hold potentiometer
Flange coupling		2	• Transmits torque from motor drive to drive link
Potentiometer		1	• Allows for precise control of drive link

[2] Not including fasteners

Drive Link		1	• 12" in length, laser cut wood
Coupler Link		1	• 14" in length, laser cut wood
Table Expansion		1	• Laser cut acrylic[3], 15"x 20" surface area • Fasteners to create 12" link length
Linear Actuator		1	• Linear actuator to drive lifting mechanism • 4" max displacement, 200N max force
Linear Actuator Fittings		2	• Connects actuator to table assembly • Helps with alignment and allows for actuator to transmit force to lifting mechanism • Combination of 8020, angle brackets, fixed to each other with drawer slides
Base Links		2	• Provide support, stability, and constraint to the structure
Slotted Links		4	• Hollow design with a track to allow for pin-in-slot sliding of crossing links • 4 pieces of laser cut wood glued together
Crossed Links		4	• 32" laser cut wood • Pin joint in middle, one end • Pin joint with attached roller on other end • 4 additional interlocking pieces for support
Table top support pieces		2	• Provides support and stability to thin acrylic tabletop

[3] Later changed to a lightweight foamcore material due to current restrictions with the motor driver.

Table top		1	● Laser cut acrylic, 30”x20” surface area

7. Bill of Materials

Bill of Materials

Name	#	Part #	Cost	Marketplace
5mm shafts	1	a15113000ux1262	$6.44 each	Amazon
5mm shaft flange	5	B07PLB2P4W	$6.89 each	Amazon
5mm shaft bearing	1	a19040300ux0206	$6.99 each	Amazon
Hinge	1	181412	$4.81 each	Amazon
Worm Gear	1	M6180801074	$11.00 each	Amazon
1/4" shaft collar	2	C-025X20	$19.49 each	Amazon
5mm to 6mm coupler	1	a18121800ux0744	$8.69 each	Amazon
M6 Nuts	1	5165782	$7.49 each	Ace Hardware
M6 Bolts	1	5167473	$8.99 each	Ace Hardware
75:1 Metal Gearmotor 25Dx69L mm HP 12V with 48 CPR Encoder	1	4846	$36.95 each	Pololu
Drawer Slides	1	964821	$7.98 each	Home Depot
8 ft 8020 1" metal	1	1010-97	$36.45 each	McMaster
1/4" rod (36")	1	802427	$3.80	Home Depot

8. Discussion and Future Modifications

We modified our initial design once we began assembly and changed some of our parts to overcome various forces. Our initial linear actuator was not powerful enough to raise or lower the table, so we switched to a more powerful linear actuator. This linear actuator had a shorter stroke length of 4 inches compared to the initial actuator's stroke length of 11.81 inches (300 mm). As a result, we had to modify the cross links, moving the mounting point for the linear actuator. We also added pieces to the links to make the links I-beams, increasing the strength of the links (see Fig. 28). Additionally, we replaced the ¼" rods that connected the two sides of the table and went through the linear actuator ends with 8020 metal because the ¼" rods bent inwards from the force of the linear actuator (see Fig. 29). We also added sliders across the 8020 metal because the 8020 was free to rotate otherwise (see Fig. 30).

In addition to the linear actuator, we also needed to replace the original stepper motor with a brushed DC motor, as the stepper motor we had was slightly faulty, and unable to run at the required speed. However, the motor controller shield we have can only output a max current of 0.6A, much below the 6A stall current of the motor. While 0.6A is enough to expand the table in its final form, it was not enough for the original design, which called for an acrylic expansion instead of foamcore. With increased resources, we could replace the motor controller with a high powered one, allowing us to use the originally intended materials.

In the future, we would like to use a drawer slider rather than wheels with bearings to have sliders that are smoother and toleranced better. Additionally, we would like to replace the plywood links with thicker wood but preferably a metal like steel or aluminum. This would help with stability of the table as well as ensure the links cannot bend or warp like wood. While, adding pieces to the links so that they are I-beams helped with stability, the links were still able to bend and the tabletop was able to not remain parallel. Steel or aluminum links would help reduce the jamming that would occur from this.

It would also be nice to pick out a linear actuator that had the desired stroke length that we needed to meet our minimum and maximum heights of the table. Because we needed to switch out the linear actuator to a stronger one, we were fixed on stroke length due to the resources we had available. Being able to have a motor that had enough force to raise and lower the table and the stroke length that matched the slider travel would allow us to meet our specifications as well as mount the linear actuator in a more ideal location such as under the tabletop or on the ground.

In addition, the stresses exerted on the worm gear would be addressed in a more market-ready prototype. While the non-backdrivable nature of the worm gear mechanism does allow the expansion to stay horizontal without constant power, the forces exerted on the worm axle itself causes deflection in the 3D printed axle holders, which we assumed would be rigid in our original design. An improved worm gear drive would either include additional bracing for the axle holders, or, ideally, a tightly-toleranced worm drive gearbox.

For some final touches, the real product would have a tabletop made out of wood rather than acrylic. The acrylic was used in our prototype to enable easy visualization of the mechanisms. Additionally, we would mount the electronics underneath the table but still have a cutout for the switches that control the mechanisms. The electronics and motors would also have enclosures to reduce the chance of children sticking their fingers into the motor or something getting caught in the electronics.

Fig 28. Added support on either side of links to create I-beams

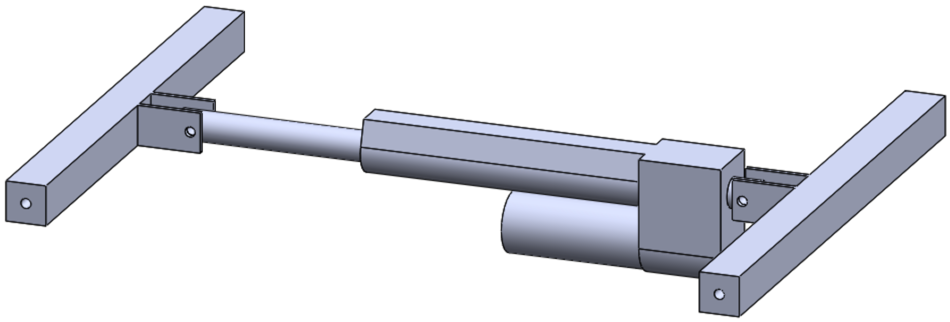


Fig 29. 8020 metal connected to the ends of linear actuator for more rigidity
(actuator would bend ¼” rods)

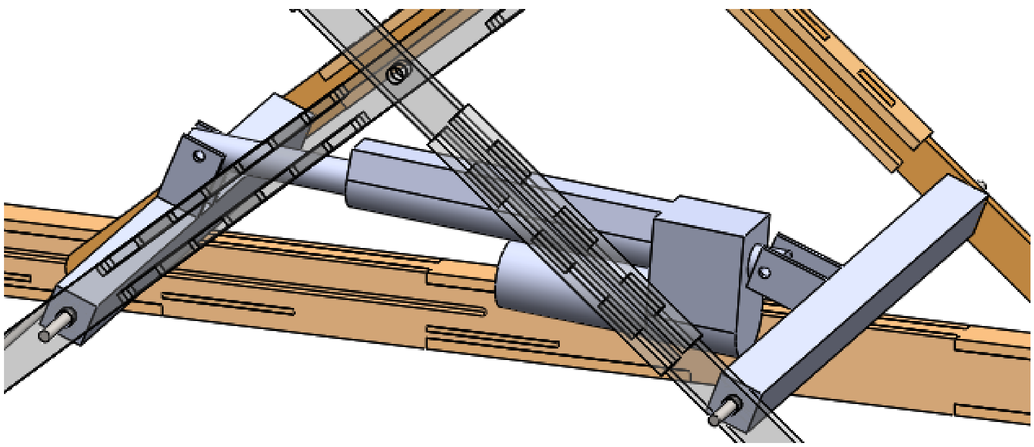


Fig 30. 8020 free to rotate (added sliders to prevent this)

9. References

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10. Appendix

Arduino Code:

```
#include <AFMotor.h>

AF_DCMotor expand(1);
AF_DCMotor lin(3);

const int potMin = 62;        // furthest up
const int potMax = 240;       // furthest down

void setup() {
  Serial.begin(9600);
  expand.setSpeed(255);
  lin.setSpeed(255);
}

void loop() {
  int expDir = (analogRead(A3)/1000) - (analogRead(A2)/1000);
  int potVal = analogRead(A5);
  if (expDir == 1 && potVal < potMax) {
    expand.run(FORWARD);                    // pot increases, expander goes down
  } else if (expDir == -1 && potVal > potMin) {
    expand.run(BACKWARD);                   // pot decreases, expander goes up
  } else {
    expand.run(RELEASE);
  }
  int linDir = (analogRead(A0)/1000) - (analogRead(A1)/1000);
  if (linDir == -1) {
    lin.run(FORWARD);
  } else if (linDir == 1) {
    lin.run(BACKWARD);
  } else {
    lin.run(RELEASE);
  }
  Serial.println(String(expDir) + ", " + String(linDir) + " - " + String(potVal));
}
```