Tyler Team 8

"Lord of the Bridges"

Advisor: Dr. Barakat

Sponsor: Dr. Garcia for The Department of Mechanical Engineering

Leader: Garrett Klein

Secretary and Treasurer: Breena Hughes

Communications Officer: Tyler Williams

Members: Joseph Ruesewald, Abdulrahman Jijakli, James Florek, Eutrope Sague



To design and build a device that automates the registration testing, and results' presentation of the Popsicle Bridge competition carried out by the Alief School District.

Table of Contents

1. Executive Summary *1*

2. Introduction and Problem Description *1*

3. Requirements and Constraints *2*

3.1 Strength **3**

3.2 Dimensions and weight **4**

3.3 Relevant Standards **4**

4. Design Considerations *4*

4.1 Power **4**

4.2 Loading mechanism **5**

4.3 Load Sensing **5**

4.4 Controller **5**

5. Final Design *6*

5.1 Overview of the Table **6**

5.2 Loading Mechanism **7**

5.3 Loading Sensor **8**

5.4 Power **9**

5.5 Controller **9**

5.6 System Operation **10**

5.7 Registration **11**

5.8 System functional diagram **12**

5.9 Safety and risk analysis **13**

6. Testing *14*

6.1 Load sensor calibration **14**

6.2 Final Simulations 15

7. Cost Analysis 16

7.1 Bill of Materials and Detailed Budget 16

7.2 Economic Feasibility 18

8. Discussion 20

9. Conclusion 21

10. References 21

Appendices 22

A. Poster and Sign Off Sheet 22

B. Timeline and Milestones 24

C. Responsibility Matrix 30

D: Mechanical Assembly Drawings 31

E. Electrical Circuits and Technical Specifications 42

F. Design Calculations 45

G. Experimental procedures and Results 55

H. Program Coding 56

I. Cost Analysis 63

J. Acceptance Criteria 64

Table of Figures

Table 2.1 Popsicle Bridge Competition Rules for different age groups……1

Table 3.1 Requirements specified by sponsor…….2

Table 3.2 Maximum Load Requirements for the popsicle bridge testing device…….3

Figure 5.1 Modular diagram of the main parts of the popsicle bridge testing system……7

Figure 5.2 LIN-ACHD Linear Actuator to be used for bridge loading operation……...8

Figure 5.3 'S' Type Load Sensor selected to measure loads exerted on samples by the popsicle bridge testing device…….…...8

Figure 5.4 Power Diagram of the popsicle bridge testing apparatus……...…….9

Figure 5.5 Flow chart of popsicle bridge testing system operations……..…….…….11

Figure 5.6 Logical model of registration process……..……12

Figure 5.7 Black box diagram of popsicle bridge testing apparatus……...……13

Table 5.1 Tipping calculation results for popsicle bridge testing assembly…...……14

Figure 6.2 Plot of 'S' Type Load Sensor calibration test…….……15

Figure 6.3 Test 1 Simulation results of popsicle bridge testing apparatus…….……16

Table 7.1 Comparing costs between production quantities of testing apparatus…....……18

Table of Nomenclature

Symbol	Description	Units
P	Pushing force	Lbf or N
W	Weight force	Lbf or N
N	Normal force	Lbf or N
f	Friction force	Lbf or N
fmax	Maximum friction force	Lbf or N
μs	Coefficient of static friction	unitless

1. Executive Summary

The purpose of this project is to design and build a device that will automate the testing procedure and result's presentation for popsicle bridge competitions. A team of engineering seniors at UT-Tyler, composed of one electrical engineering student and six mechanical engineering students carried out this project as their senior capstone design project. A device was designed, built, and tested, based on specifications provided by the competition organizers that can automate the testing process of popsicle bridges made by grade students from registration to ranked results. The device employs a linear actuator that will load the bridges with a gradually increasing force until failure, while a load cell is picking up the loading force values. Registration information will be collected before the tests and test results will be added to each contestant after the test to build a record. Individual live data from each test as well as final ranking of records will be displayed on a large size monitors during and after the competition is completed. Results from testing the device show consistent and reliable operation while guarding the safety of the device and contestants. The sponsor was satisfied with the outcome of the project.

2. Introduction and Problem Description

The Alief school district in Houston holds an annual competition for its students challenging them to build the strongest popsicle bridge. The competition is split into three divisions based on the students' age: elementary, middle, and high school. Table 2.1 lists the divisional rules.

Table 2.1 Popsicle Bridge Competition Rules for different age groups

Division	# of popsicle sticks allowed	bridge dimensions

Elementary School	100 Sticks	1'x4"x4"
Middle School	300 Sticks	2'x4"x4"
High School	500 Sticks	3’x4”x4”
Allowed for all divisions	Use 8 oz standard school glue like Elmer	

During the competition, all bridges are loaded gradually at the middle until they break. The winning bridge is the one that can take the most load in its group until failure. Currently, the bridges are loaded and tested using a hand cranked winch and an S-type load cell. When the competition was first started, this was a widely accepted and viable testing method. However, as the number of contestants grew, the hand cranked system became less efficient and henceforth less desirable. Due to the growing popularity of the competition and the large number of contestants involved, an automated testing apparatus became necessary. Team 8 was tasked with designing and producing this automated system.

3. Requirements and Constraints

The produced device must allow registration, automated testing with live recording and display of loads exerted on a bridge, compile registration records and results, and rank, with results’ display, popsicle bridges for every division of the competition. Table 3.1 details the complete list of specifications provided by the sponsor.

Table 3.1 Requirements specified by sponsor

Specifications	Parameter	Value	Parameter	Value	Parameter	Value
Table Dimensions	Height	min. 4' max. 4.5'	Width	2'	Length	5'
Linear Actuator	Max Load	750 lbf	Stroke Length	24"	Power	110VAC

S' Type Load Sensor	Max Load	660 lbf				
Raspberry pi	model	3b+	Power	5v	RAM	1 gb

3.1 Strength

From previous experiences, maximum load limits were specified as listed in Table 3.2. A safety factor (S.F.) was selected to be 1.5. This safety factor was chosen in order to most efficiently address the required specification without overspending. Loading mechanisms are priced in increasing order that is proportional to their loading capacity. The device needs to be able to withstand both internal and external forces. The device must withstand vertical loading performed on the bridges, while also maintaining stability in case it was to be pushed.

Table 3.2 Maximum Load Requirements for the popsicle bridge testing device

Forces (lbf)	Horizontal	Vertical
Max (lbf)	50	500
Max w/ S.F. (lbf)	75	750

The supporting members of the system housing must be able to withstand up to 750 lbf without breaching the upper limit of its elastic modulus. The varying strengths of the bridges between divisions presents a major issue. This is due to the sensitivity ranges necessary to capture accurate readings from low strength, to high strength bridges. This has a significant impact on loading sensor selection.

3.2 Dimensions and weight

The lengths of the bridges are determined by the divisional rules, making it necessary to implement support[1] modularity- having three different configurations. Given the educational nature of this competition, full operational visibility is desired. This gives the contestants (grade schoolers) exposure to the engineering world. This means the apparatus must be tall enough to allow for both the bridge and the loading mechanism to be seen by the contestants. To maintain safe operation with full visibility, a transparent shield or barrier will be needed. The design must allow for mobility. Moreover, efficient use of material in construction is a necessity to allow for resistive strength while maintaining the ability to be moved from operational locations.

3.3 Relevant Standards

Supplemental documentation and required deliverables were provided by both the project sponsor, Dr. Andres Garcia, and the Senior Capstone Design I advisor for TYL8, Dr. El-Kishky, regarding the relevant standards for the Senior Capstone Design project. The *Senior Capstone Design Project Proposal* documentation supplied to TYL8 contained a special delivery request for the relevant standards needed, requiring the project follow the 2020 Alief Popsicle Bridge Competition rules, regulations, and guidelines.

4. Design Considerations

4.1 Power

Two choices were available for powering the system, Battery vs. Main 110VAC supply. Based on the total power needed by the system and the constraints on budget, the decisions were to use main 110VAC power supply.

[1] Surface(s) on which the popsicle bridge will rest for testing

4.2 Loading mechanism

The key factors to consider were cost, ease of use, and simplicity of maintenance. A linear actuator was selected as the base for the loading mechanism. A linear actuator consists of a ring and worm gear mesh that provide the linear motion. The inputs for this type of system are basic motor windings which make it simple to test and operate. Bottom side loading was selected because top loading would require changes to the dimensions of the base holding the test sample to allow contact with the top surface of the bridge without interference with the trusses. Therefore, bottom-sided loading became the optimal selection. The drawback of this is the need for a connection surface to be mounted to each bridge being tested, which takes away some automation.

4.3 Load Sensing

The team was provided with an ‘S’ type tensile and compressive sensor used in previous competitions. As it was free, this became the standard loading sensor for the device. Other choices included piezo-electric compression sensors, compression-force transducers and even displacement gauges. Since it was decided to load from the bottom of the bridge, the ‘S’ Type sensor was optimal. This is due to its ability to handle tensile loads as well as compressive while maintaining similar costs to the other choices. This makes the design modifiable for alternative uses, thus increasing the range of use of the machine.

4.4 Controller

The final device is automated to avoid human error using a single user input. The minimal requirements that the operating device needs include inputs for the loading sensor, processing ability to run an integrated program, the available RAM for the programming, data storage using a location in a network, and output back to a display. The device in question needs

a fully integrated micro computer to optimally handle both hardware functioning as well as network computing.

5. Final Design

5.1 Overview of the Table

As seen in figure 5.1, the device is a fully enclosed table powered by a linear actuator. The linear actuator is connected to the S-type load cell which is then attached to the connecting apparatus placed inside the bridge that is currently being tested. The table features a modifiable top to account for the different lengths of bridges between the three divisions. The top uses dowel rods as soft[2] connection points. The legs of the table are cut so that the outside of the 2x4's that are connecting them are flush with the legs. Surfaces at both the top and the bottom are composed of 1" thick plywood, making for a sturdy point of contact for the actuator and bridge under load. The dimensions of the table parts and subassembly can be found in Appendix D.

[2] Not fixed to surface; one or more degrees of freedom

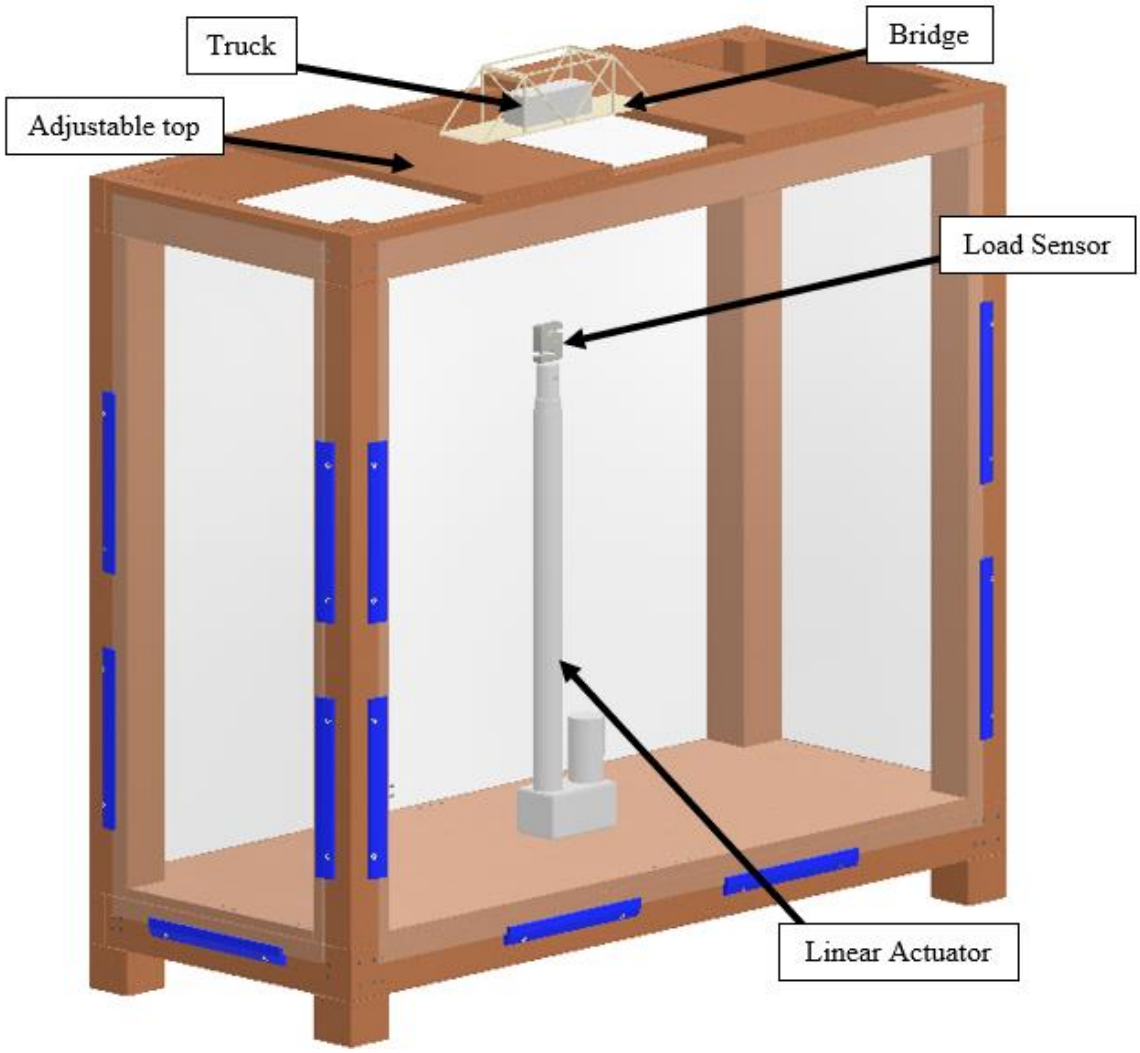


Figure 5.1 Modular diagram of the main parts of the popsicle bridge testing system

5.2 Loading Mechanism

The final design utilizes a linear actuator to load the bridge gradually and reach failure. Figure 5.2 shows the selected actuator. A detailed drawing of the selected actuator can be found in Appendix D. This actuator was chosen for its rated loading capacity equal 750 lbf which is the required loading capacity determined in the requirements Table 3.1. The full list of specifications can be seen in Appendix E.



Figure 5.2 LIN-ACHD Linear Actuator to be used for bridge loading operation

5.3 Loading Sensor

Figure 5.3 shows the S-type load cell used to measure the load exerted on the popsicle bridge by the linear actuator during testing. This type of load cell offers a range that suits this application Specifications of this load cell are provided in Appendix E. This load cell will be located between the linear actuator and the bottom of the bridge hanging by braided steel ropes in two opposite directions. The load cell chosen has a range of 0 to 300 kg (660 lbf).



Figure 5.3 'S' Type Load Sensor selected to measure loads exerted on samples by the popsicle bridge testing device.

5.4 Power

Figure 5.4 shows a simple diagram of the power circuit for the device. The requirements were met by utilizing main power via the 120 VAC configuration of the motor windings. The controller of the device operates off 12 DC by way of a 10/1 step down transformer. The outputs of the controller are 5 DC. A full set of electrical diagrams and specifications can be found in Appendix E.

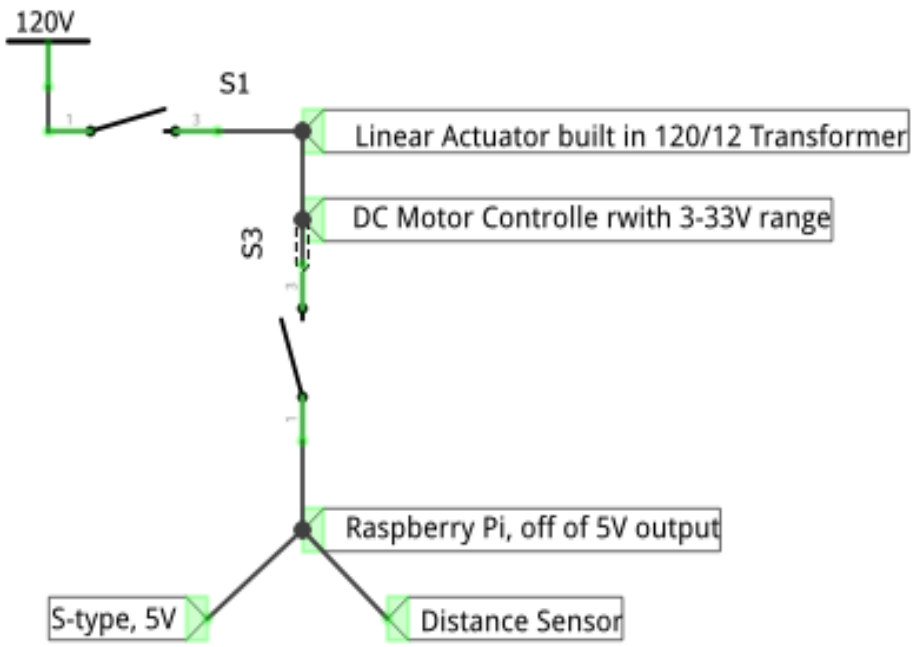


Figure 5.4 Power Diagram of the popsicle bridge testing apparatus

5.5 Controller

The team selected a Raspberry Pi model 3 B+ for initial software development and testing which was supplied by the sponsor. The full list of specifications and pin diagrams for this microcontroller can be found in Appendix E. This controller is outfitted with a full-sized HDMI port making it easy to output to common displays. The CPU and RAM specifications are adequate to run the program without becoming encumbered and the 40-pin GPIO gives plenty of

room for modifications and improvements to the design. The Raspberry Pi uses Python which is preloaded onto the Raspian OS. Python is the preferred language to use in this design.

5.6 System Operation

Figure 5.5 shows a flow chart of the popsicle bridge testing system operations. All system operations will be controlled through the software residing on the Raspberry Pi using the Raspian OS. Testing is conducted after competitor's data is entered and saved. Testing consists of programmed gradual loading of the sample belonging to the registered competitor while reading the load exerted from the load cell. This is carried out at a frequency of # Hz. When the loading cell data shows a sudden decrease in loading that is checked more than once, operation is stopped, and the highest recorded load is displayed as the breaking load.

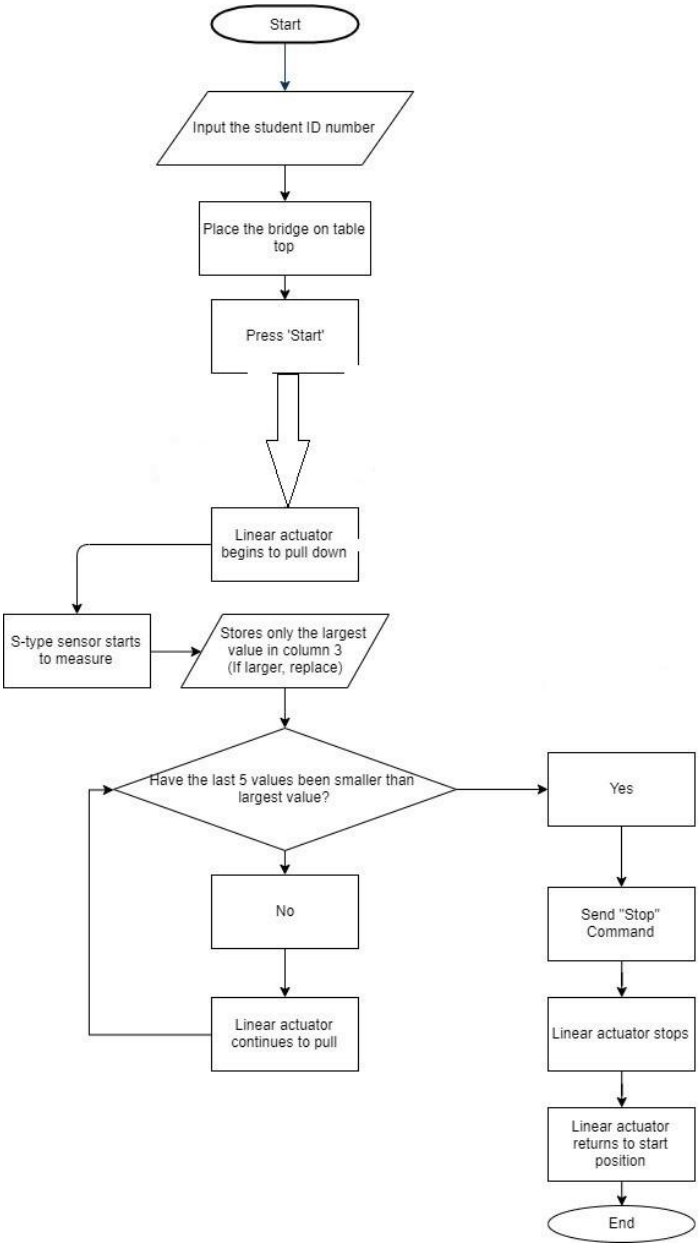


Figure 5.5 Flow chart of popsicle bridge testing system operations

5.7 Registration

The registration process uses Google Forms to collect each teams' name, school name, competition level, and mass of popsicle stick bridge. Google Forms was selected because it can be accessed by any device with an internet connection, offloads the registration process from the Raspberry Pi, and automatically creates a Google Sheet containing the collected information.

The flowchart shown in figure 5.6 shows the logical flow of the registration procedure. At the completion of the registration process and testing, the results are then compiled and organized, ranking the bridges on load. The winner is determined for all three divisions.

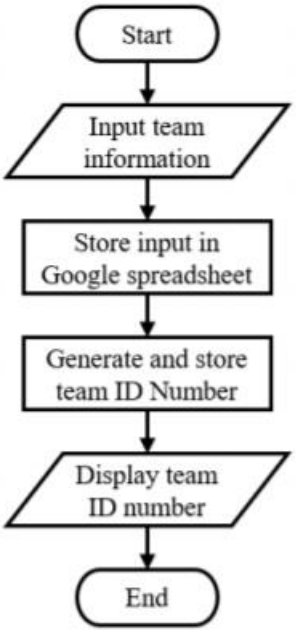


Figure 5.6 Logical model of registration process

5.8 System functional diagram

Figure 5.7 shows the black box diagram of the system. The system will have inputs of electricity for powering the device, registration data provided by the students, and the popsicle bridges made by each individual student. The system outputs include heat and sound from the powered device, the testing results in ranks, and the broken bridge.

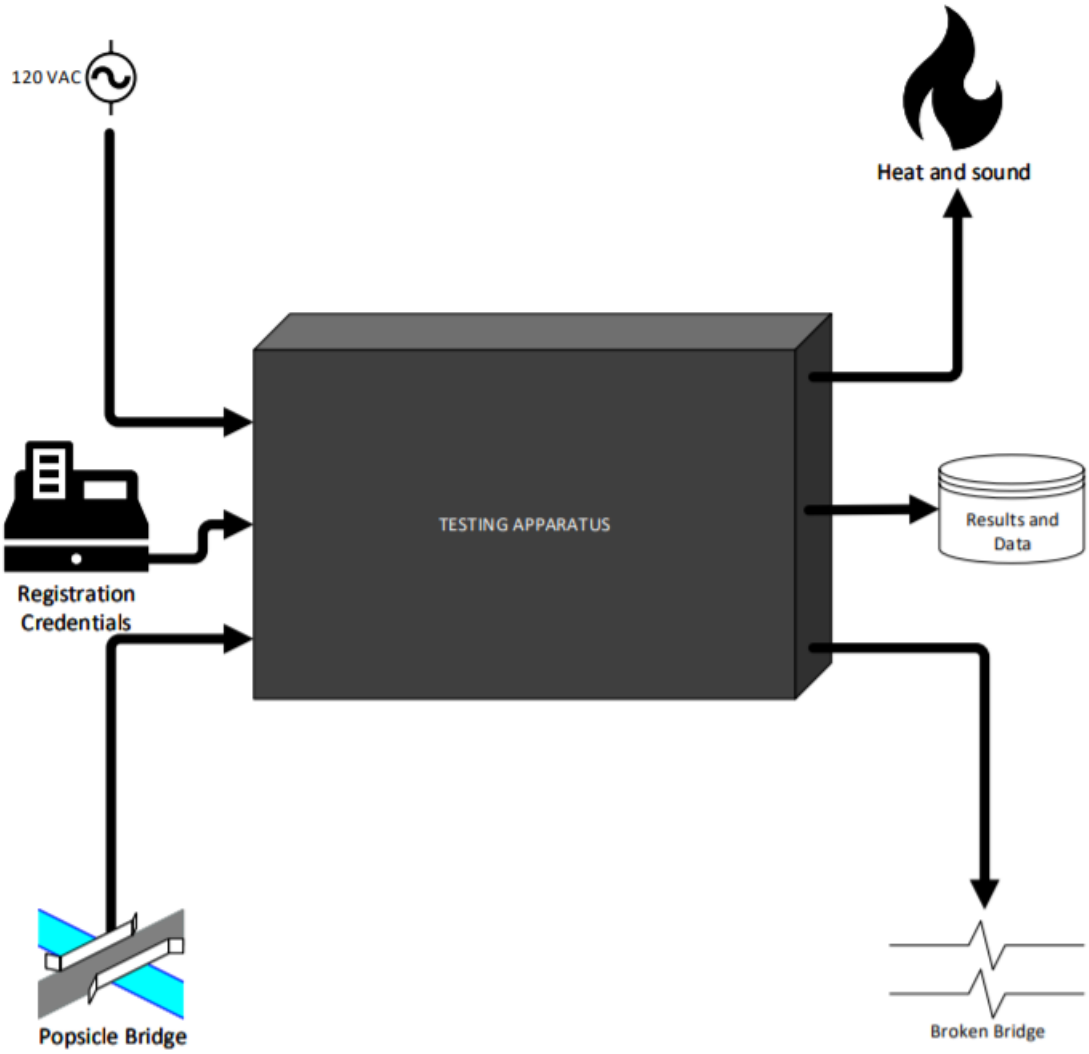


Figure 5.7 Black box diagram of popsicle bridge testing apparatus

5.9 Safety and risk analysis

The paramount concern of the team in designing this device is safety. The requirements dictate that the students must be able to see that device operate while maintaining protection from unauthorized interaction with the powered mechanisms and subsystems. The team has addressed this by utilizing plexiglass sheets on all sides of the device. Given the table's dimensions, some extra precautions had to be taken to ensure stability upon a student

accidentally running into the table. The team analyzed this using appropriate calculations for tipping load limits. Calculations were performed using an estimated mass of the entire system. This was done by finding the volume of the wood and multiplying it by the density. Only the wood was considered as this is the heaviest part of the design. Calculations were performed on both a light-weight wood (birch) and a heavy-weight wood (oak). This was done to verify the calculations were performed correctly as the heavier wood should be sturdier. Table 5.1 shows the results of the tipping calculations. Case 1 refers to a pushing force applied on the longer side of the table at the top and case 2 refers to a pushing force applied to the shorter side of the table applied at the top. Calculations were done for both the table only and the full assembly. Appendix F includes the details of these calculations.

Table 5.1 Tipping calculation results for popsicle bridge testing assembly

Cases	Table Only	Full Assembly
1	145 N (32.6 lbf)	185 N (41.6 lbf)
2	363 N (81.6 lbf)	462 N (103.9 lbf)

6. Testing

6.1 Load sensor calibration

An experimental setup was built to calibrate the S-type load sensor. Figure 6.1 shows a schematic of the experimental setup. The sensor was gradually loaded from 0 to 40 lbf and back down to 0 and its output was measured by a Voltmeter. The plot shown in Figure 6.2 shows the results of the test. The outputted values were the same on both the loading and unloading sequences for each respective value of force exerted on the sensor. The raw data from the test

can be found in Appendix G. The coefficient for calibration is found as the slope of the plot. Using this coefficient, the system is ready to operate with the outfitted sensor.

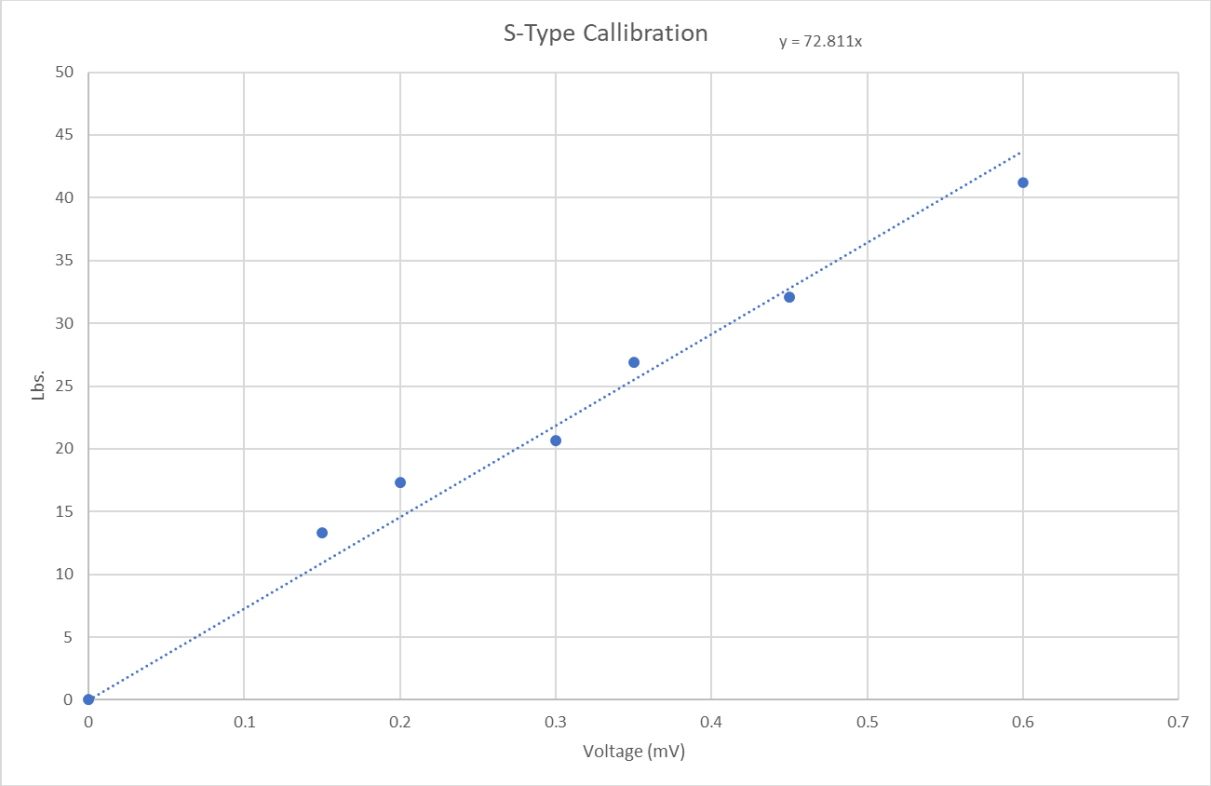


Figure 6.2 Plot of 'S' Type Load Sensor calibration test

6.2 Final Simulations

Upon completion of sensor calibration, the final step was to run simulation bridge tests. Sticks were used as substitutions for popsicle bridges to save time in this stage. The sticks were placed on the adjustable tops like a popsicle bridge, loaded gradually until failure, and the highest load value was recorded. Figure 6.3 shows the plot of a successful test run on the device. The final value given in the plot is the peak force recorded by the device before failure. The full list of tests and resulting data can be found in Appendix G.

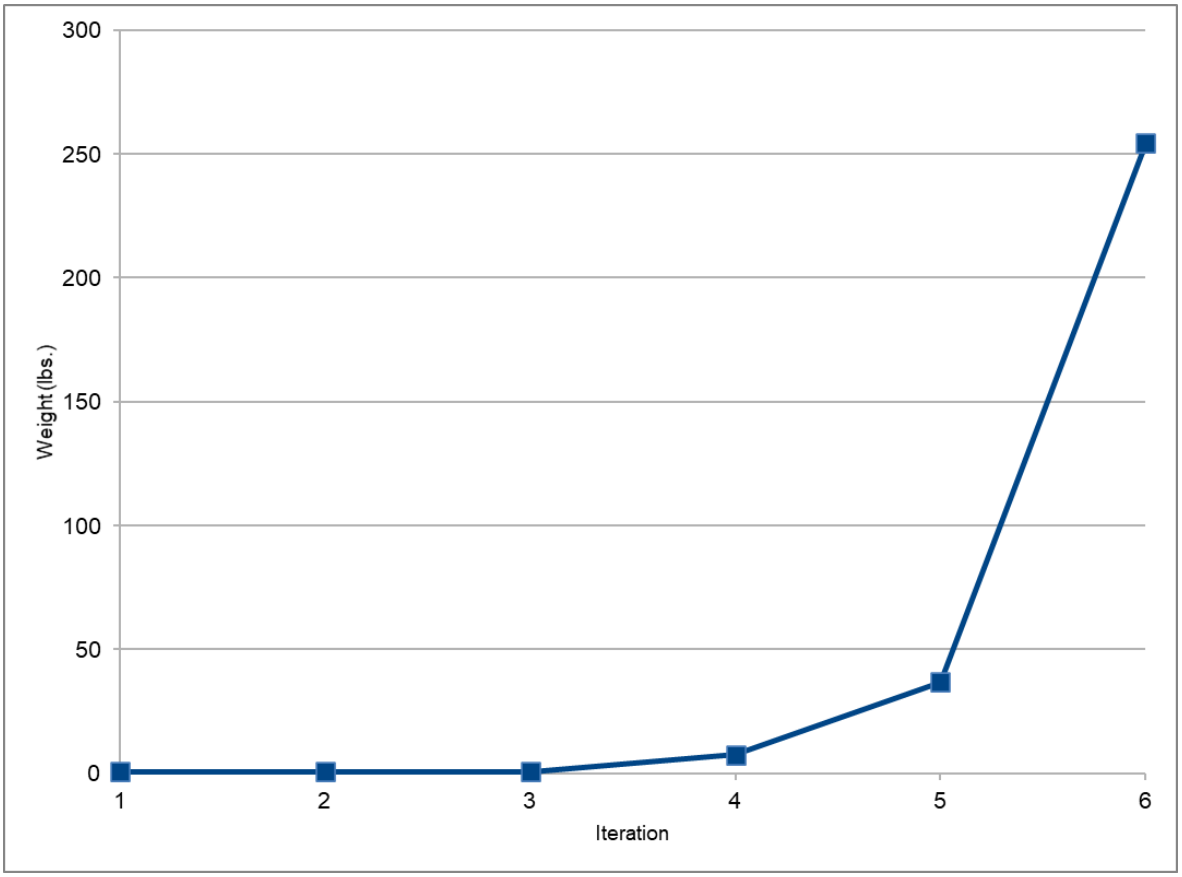


Figure 6.3 Test 1 Simulation results of popsicle bridge testing apparatus

7. Cost Analysis

7.1 Bill of Materials and Detailed Budget

Relating to the bill of materials and project budget, examine the motives, logic, and decisions behind the materials/components selected for The Lord of the Bridges 2020 Senior Capstone Design project, and the price performance tradeoff used to simultaneously achieve optimal performance alongside fast and accurate real-time competition results; all whilst managing the team's donated $1000 budget (individual team member purchases excluded).

The overall breakdown of the materials purchased, or the bill of materials (B.O.M.), for this project, under the donated budget mentioned above, can be found in Appendix I. Down at the

bottom of the BOM, the total cost of all the purchased items inside the allotted budget, which is roughly $820.15, is shown, and highlighted in yellow. By thoroughly researching the individual components and their counterparts, the team was able to stay $179.85 under budget. As stated above, the team's donated budget does not include personal team member purchases for this project. Factoring in the costs outside of the donated budget (purchases not included in the B.O.M) that the team – or individual team members – personally spent on the project, including additional materials, parts, and components (etc.), adds up to approximately $700-$1,000. For simplicity, the total overall project cost can be reasonably estimated at around $2,000.

When choosing parts for the project, the team decided to start with the most essential components that provide the mechanical advantage; typically, the actuator subassembly and the center/bench subassembly (all parts listed below can be found in the B.O.M. under BOM Levels 2.00 and 4.00). The parts that dealt with the mechanical advantage in this design were both the linear actuator and exterior body of the table. In choosing the right linear actuator, it was essential to assess its maximum potential for lifting/lowering heavy loads and a stroke length nearly 1/3 of the total height of the table; in this case, the ability to handle dynamic loads over 500lbs, and a stroke length around 18 inches. For the exterior frame of the table, which is made primarily out of wood, the choices came down to lumber prices and the relative strengths of each. Due to its cost effectiveness, high strength, and its hardness (around 870lbf), the lumber for the exterior frame purchased was standard Yellow Pine.

The next essential components considered for the design dealt with the electrical side of the project, or more specifically, the parts that will provide computing power and supply, input/output (or I/O) capabilities for automation and control, load cells, pressure sensors, and an LED screen for displaying results. The electromechanical components that were purchased to

satisfy these design requirements can be found in Appendix I (see BOM Level 1.00: Raspberry Pi Control Module / Electrical). The total cost for these components were originally estimated to cost around 30-40% of the donated budget; however, with donated parts from previous design projects, and other freely acquired parts, the total cost ended up being around 20%, or $195.

The remaining components purchased that strained the budget dealt primarily with the aesthetics, cosmetics, mobility of design, and safety of the design. Aesthetic components found on the B.O.M. include materials such as wood stain, sanding equipment, and electrical harnesses for cable management. The mobility component that were necessary for overall mobility of the project, is shown in BOM Level 5.00: Bottom/Wheels Subassembly. Safety of the design was thoroughly discussed and considered by the team because of the importance of creating not only an updated model of the previous system, but an automated model that reduces time, effort, and most importantly, the risk factors involved. To help minimize the risk factors involved during the testing and competition phase (environment being a school with hundreds of kids), the decision to enclose the bench/table testing apparatus was considered. As shown in the B.O.M. (BOM Level 6.00: Waste/Plexiglass Subassembly), the purchased items including plexiglass, and plexiglass holders were purchased. The choice of 1/8” plexiglass was decided to help reduce the possible ejections of popsicle pieces outwards towards the spectating kids and ensuring a safe operating area for the competition duration.

7.2 Economic Feasibility

Table 7.1 Comparing costs between production quantities of testing apparatus

Quantity	Unit cost
1	$ 850
100	$ 750

1000	$ 650

Table 7.1 shows the estimated costs associated with production quantity. As would be expected, the most expensive unit cost will be for manufacturing only 1 unit. As more and more units are manufactured, the unit cost can be brought down. This is due to a multitude of factors.

Firstly, by buying raw material in large quantities, you can ask for a wholesale discount which usually increases the more you buy. Secondly, Shipping costs can also be reduced on a per piece basis when you order in large quantities. Thirdly, when you are manufacturing in large amounts, you can implement an assembly line system which reduces wasted labor and allows for better quality control and faster manufacturing time. Furthermore, many lucrative markets can be accessed only when you are capable of manufacturing in large quantities, which increases your market share and reduces your risk, thereby increasing investor confidence and securing better financing terms, which on the long run also contributes to lower costs. Last but not least, by manufacturing in large amounts and putting your product everywhere, it becomes a free marketing tool that basically secures future customers without requiring you to spend money on marketing, which yet again lowers your overall cost as marketing costs can sometimes be very huge.

Keep in mind that market prices fluctuate for a variety of factors, and sometimes companies must increase the price of their product due to shortage in raw materials. The above numbers were estimated based on other similar items that are common in the marketplace and that typically ranges between 10% to 30% of the retail price. If you need further reduction in cost price, then a much larger quantity needs to be ordered. Ordering around a million units will probably reduce the price by 50% but that is unrealistic for this product as the demand is not that prevalent.

There are other areas to cut the cost of this device besides manufacturing costs. Increasing the longevity of the device by proper maintenance and proper storage will also save money on the long run. Sharing the device with other school districts also means that fewer devices need to be bought and thereby saving a lot of money. Furthermore, renting out the device to hobbyist will bring a profit that can offset the initial costs and maybe even make this device a good investment. The options to saving money are plenty but to determine the economic feasibility, a market study needs to be done in order to determine how big is the marketplace for this product and whether or not it is possible to create demand for this product by marketing campaigns such as competitions, T.V. shows etc.

8. Discussion

Plans were made to outfit the device with more than one sensor for testing different structural attributes of the bridges. Some of the sensors that had been considered for the primary load testing were also considered for use in other respects. For example, the piezo electric pressure sensors could be placed beneath the four points of contact of the bridge to the top surface of the table, allowing for torsional analysis. The system would compare load readings at each piezo sensor to determine any buckling in the bridge. Displacement sensing is another modification made possible with this system. This would act as a deflection test for the midpoint of the bridge to determine rigidity. All modifications of this type would require editing the code as well as minor additional wiring. Some other changes include manufacturing with repeatability. This would include dimensions for the table that allow for disassembly, making it easier to produce, ship, and store the device. Additional actuation could be added to allow for automated configuration for the different divisions. An actuator would be used to change the position of the top surfaces of the table to reflect divisional rules. The bridges currently require physical

interaction with the connection plate to secure the load sensor to the bridge. Further automation to the system would include automatic connection to the bridge by way of electric interlocks. This configuration is only made possible with further development of an inductor/switch-based circuit that would lock the sensor to the bridge upon switched power and release upon removing power from the switch, like a car door.

9. Conclusion

The Alief school district's popsicle bridge competition has been stuck in the past in testing for strength. Manual load application is tedious and straining on the individual[s] in charge of supplying said load. Due to this problem, and the growing demand for a system that can help reduce time and labor, the systems/devices must become more automated. This design tests the bridges automatically and ranks the bridges using a registration interface to fully address this problem. This is done while maintaining proper visibility of the device in operation to educate the students on engineering in practice. The goal is to encourage students to pursue the STEM field in their collegiate career. The device shows students that any problem can be solved with proper identification and planning.

10. References

(1) Bassin, Milton G., et al. Statics and Strength of Materials. Glencoe/McGraw-Hill, 1999.

(2) BridgeBuildingCompetition. "Popsicle Bridge Building Competition 2019 ." 2019. PDF.

(3) IEEE. "IEEE Lesson Plan: Popsicle Bridge." 2018. PDF.

Appendices

A. Poster and Sign Off Sheet

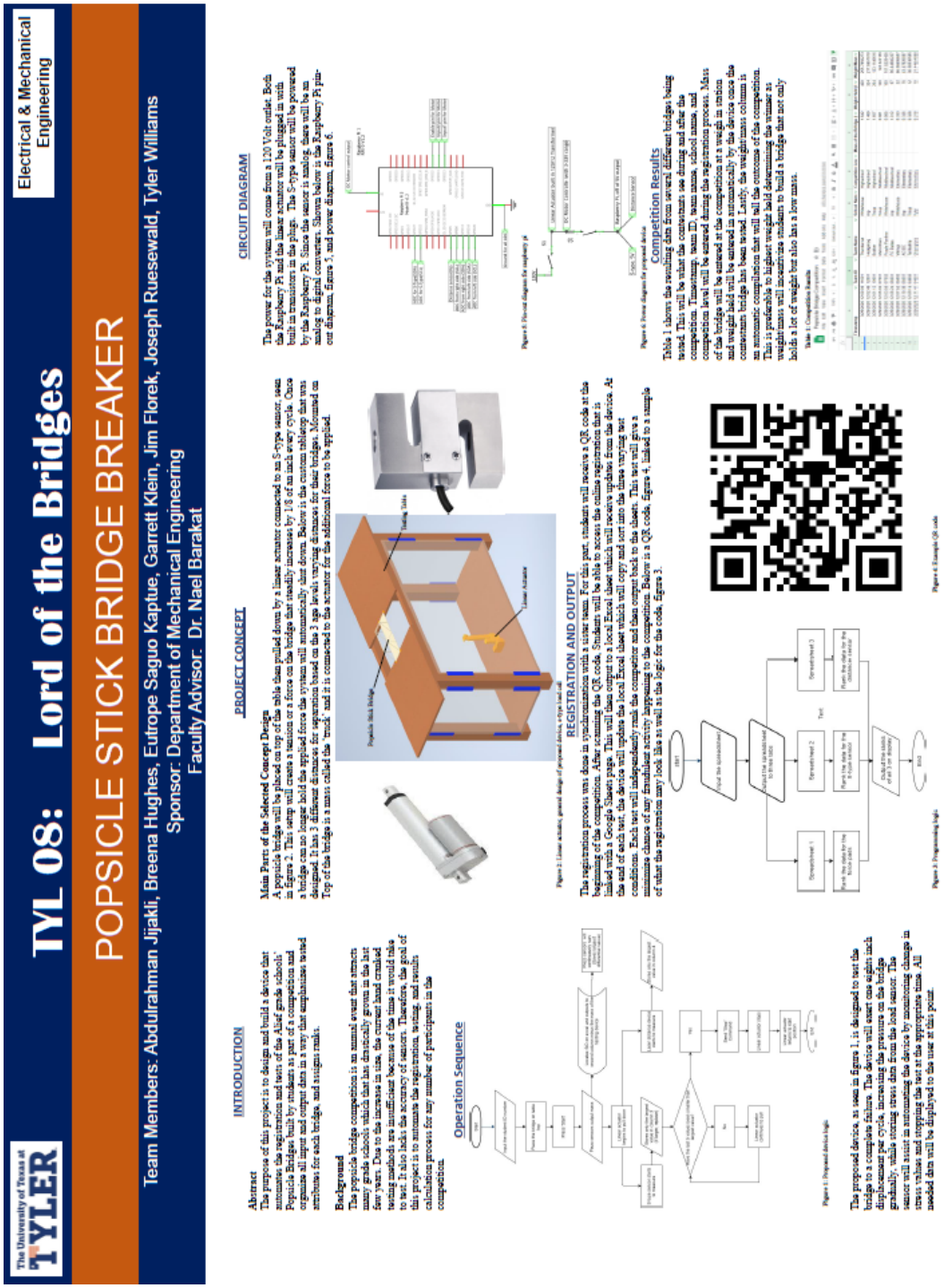


Figure A.1 Team Presentation Poster

-Entropy is absent

The University of Texas at TYLER
COLLEGE OF ENGINEERING

Department of Mechanical Engineering
Phone: +1.903.566.7003
Fax: +1.903.566.7148
Uttyler.edu/engineering

Reviewers:
- Talisin Khajorn
- Nirmala Sundararajan

Senior Design Project

Design Review Evaluation Form

Please select the type of review:

1. ***Internal (No external Customer)***
2. ***External (Includes external Customer)***

Team : Tyler 8

Item	Information	Grade
Team #		N/A
Team name		N/A
Project Title		N/A
Project Type	External / Internal	N/A
Project Sponsor		N/A
Date of Design Review		N/A
Attendees		N/A
Meeting Lead Student		N/A
Minutes Takers		N/A
Packet and Agenda distributed 48 hours ahead of meeting	Y / N	3 / 5
Quality and completeness of packet and handouts	H / M / L	8 / 10
Quality and completeness of Design details presented	H / M / L	8 / 10
Quality of team handling of the meeting and questions	H / M / L	10 / 10
Did the team achieve the goals of the design review?	Y / N / Partially	9 / 10
Advisor Evaluation		5 / 5
Result	1. Redo 2. Conditional approval to move forward 3. Unconditional approval to continue to next step	Total = 42 / 50

Comments / Conditions / Requirements for the team:

1. Detailed mechanical design is missing.
2. Detailed electrical connections must be added
3. A flowchart for the code must be

Figure A.2 Preliminary Sign-off sheet

B. Timeline and Milestones

	Name	Duration	Start	Finish	Predecessors	R... F	S
1	**Start**	**8 days**	**8/27/19 8:00 AM**	**9/5/19 5:00 PM**			
2	Start Class	5 days	8/27/19 8:00 AM	9/2/19 5:00 PM			
3	Recieve Project Details	1 day	9/3/19 8:00 AM	9/3/19 5:00 PM	2		
4	Meet Team and Set Meetings	3 days	9/3/19 8:00 AM	9/5/19 5:00 PM	2		
5	**Concept Generation**	**20 days**	**9/4/19 8:00 AM**	**10/1/19 5:00 PM**	**3**		
6	Gather Specs	7 days	9/4/19 8:00 AM	9/12/19 5:00 PM	3		
7	Brainstorming	12 days	9/13/19 8:00 AM	9/30/19 5:00 PM	3;6		
8	Idea Selection	1 day	10/1/19 8:00 AM	10/1/19 5:00 PM	7		
9	**Final Design Formation**	**12 days**	**10/2/19 8:00 AM**	**10/17/19 5:00 PM**	**5**		
10	Modeling	5 days	10/2/19 8:00 AM	10/8/19 5:00 PM	8		
11	Tweaking	7 days	10/9/19 8:00 AM	10/17/19 5:00 PM	10		
12	Sourcing	10 days	10/4/19 8:00 AM	10/17/19 5:00 PM	8		
13	**Final Reports**	**29 days**	**10/9/19 8:00 AM**	**11/18/19 5:00 PM**	**10**		
14	Peer Presentation	29 days	10/9/19 8:00 AM	11/18/19 5:00 PM			
15	Design Review	29 days	10/9/19 8:00 AM	11/18/19 5:00 PM			
16	Status Report	29 days	10/9/19 8:00 AM	11/18/19 5:00 PM			
17	**Purchasing**	**15 days**	**1/13/20 8:00 AM**	**1/31/20 5:00 PM**	**13**		
18	Initial Status Report	10 days	1/13/20 8:00 AM	1/24/20 5:00 PM			
19	Purchase Parts	5 days	1/27/20 8:00 AM	1/31/20 5:00 PM	18		
20	**Final Build**	**10 days**	**2/3/20 8:00 AM**	**2/14/20 5:00 PM**	**17**		
21	Manufacturing/Fabrications	5 days	2/3/20 8:00 AM	2/7/20 5:00 PM	19		
22	Modifications as Needed and Astetics	5 days	2/3/20 8:00 AM	2/7/20 5:00 PM	19		
23	Final Testing	5 days	2/10/20 8:00 AM	2/14/20 5:00 PM	21;22		
24	Registration Setup/Manuals	99 days	10/2/19 8:00 AM	2/17/20 5:00 PM	8		
25	Houston Competition	25 days	2/18/20 8:00 AM	3/23/20 5:00 PM	20;24;23		
26	**Final Report**	**28 days**	**3/24/20 8:00 AM**	**4/30/20 5:00 PM**	**25**		
27	Report	24 days	3/24/20 8:00 AM	4/24/20 5:00 PM			
28	Showcase	4 days	4/27/20 8:00 AM	4/30/20 5:00 PM			

Senior Design TYL8 - page1

Figure B.1 Table for Gantt Chart

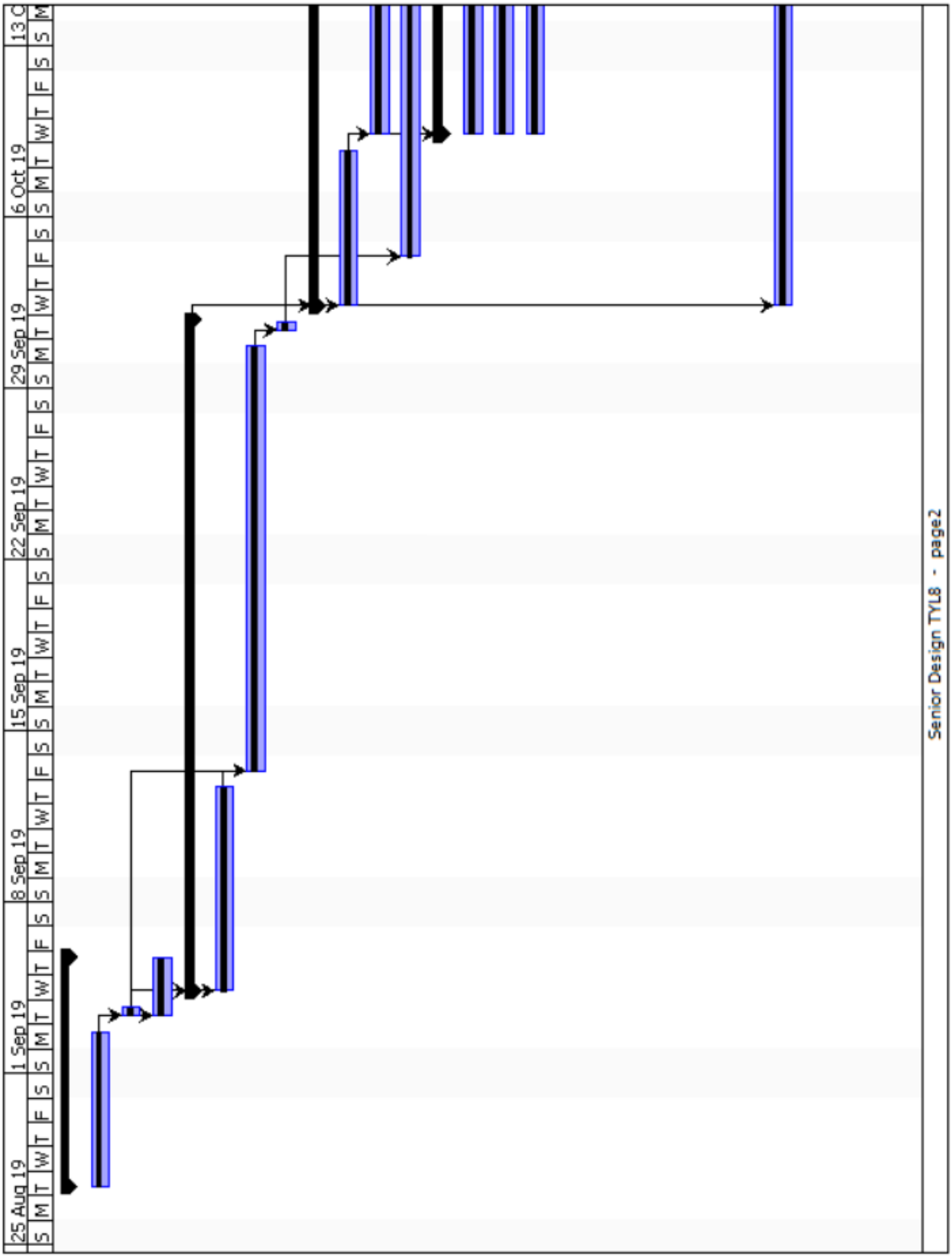


Figure B.2 Gantt Chart 1

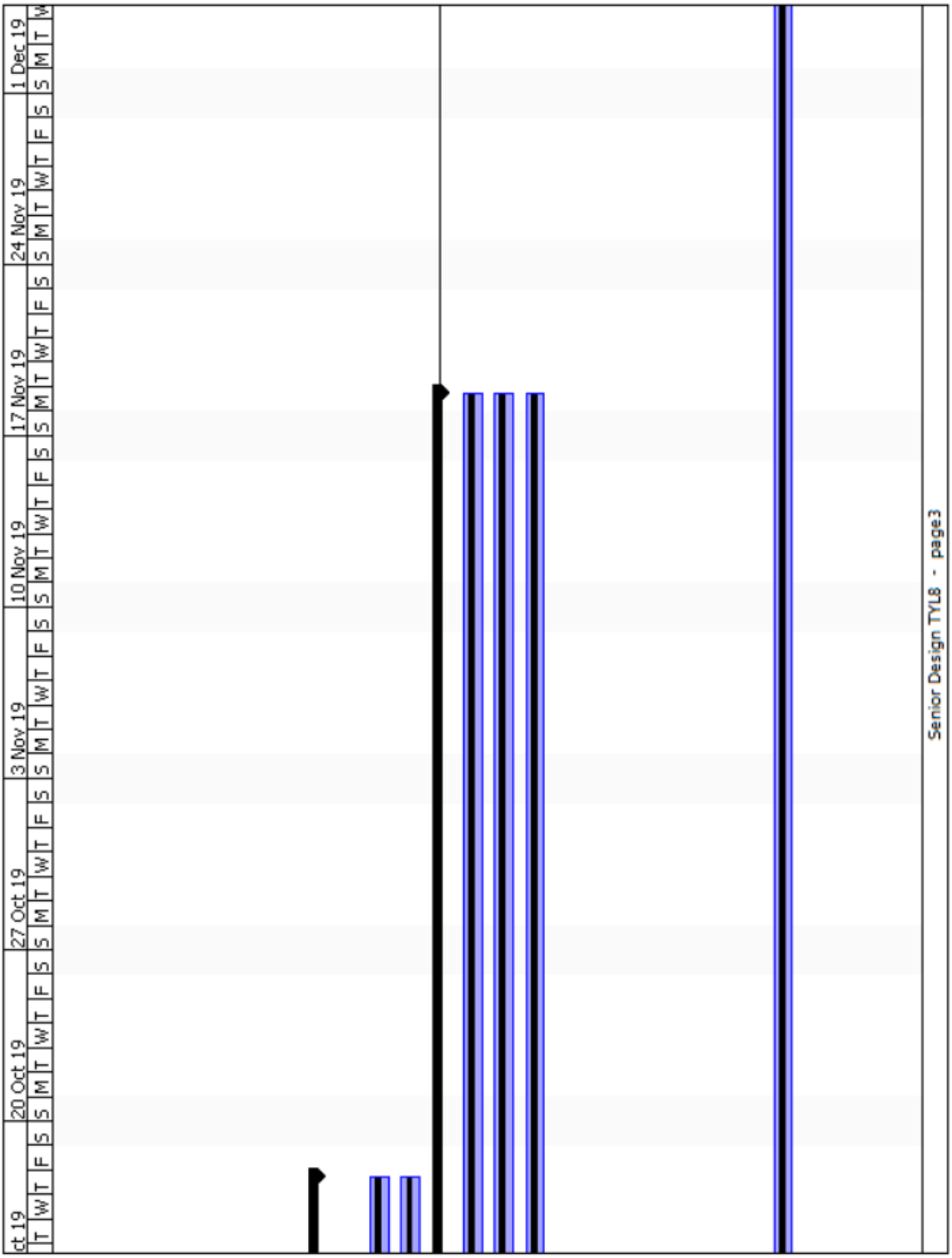


Figure B.3 Gantt Chart 2

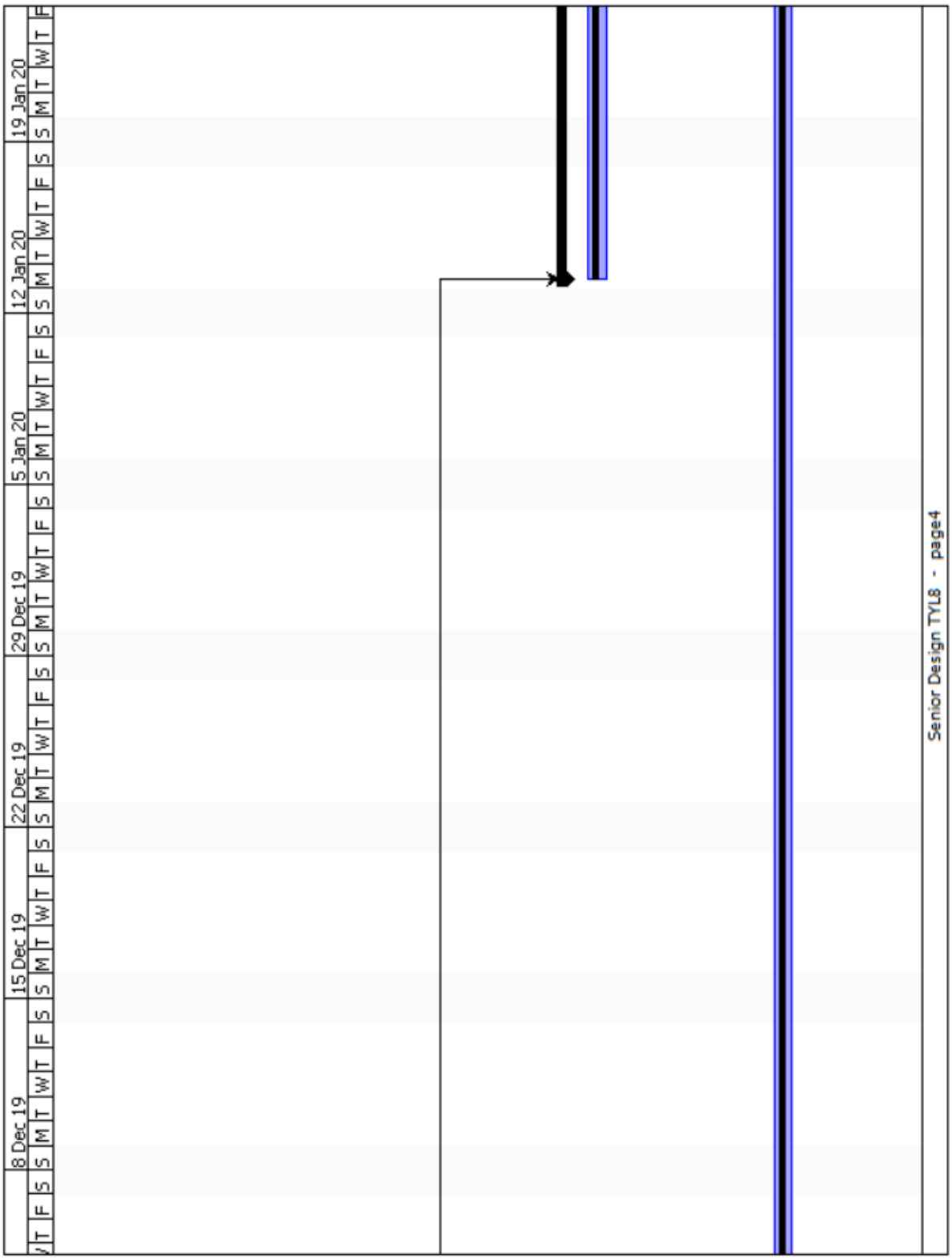


Figure B.4 Gantt Chart 3

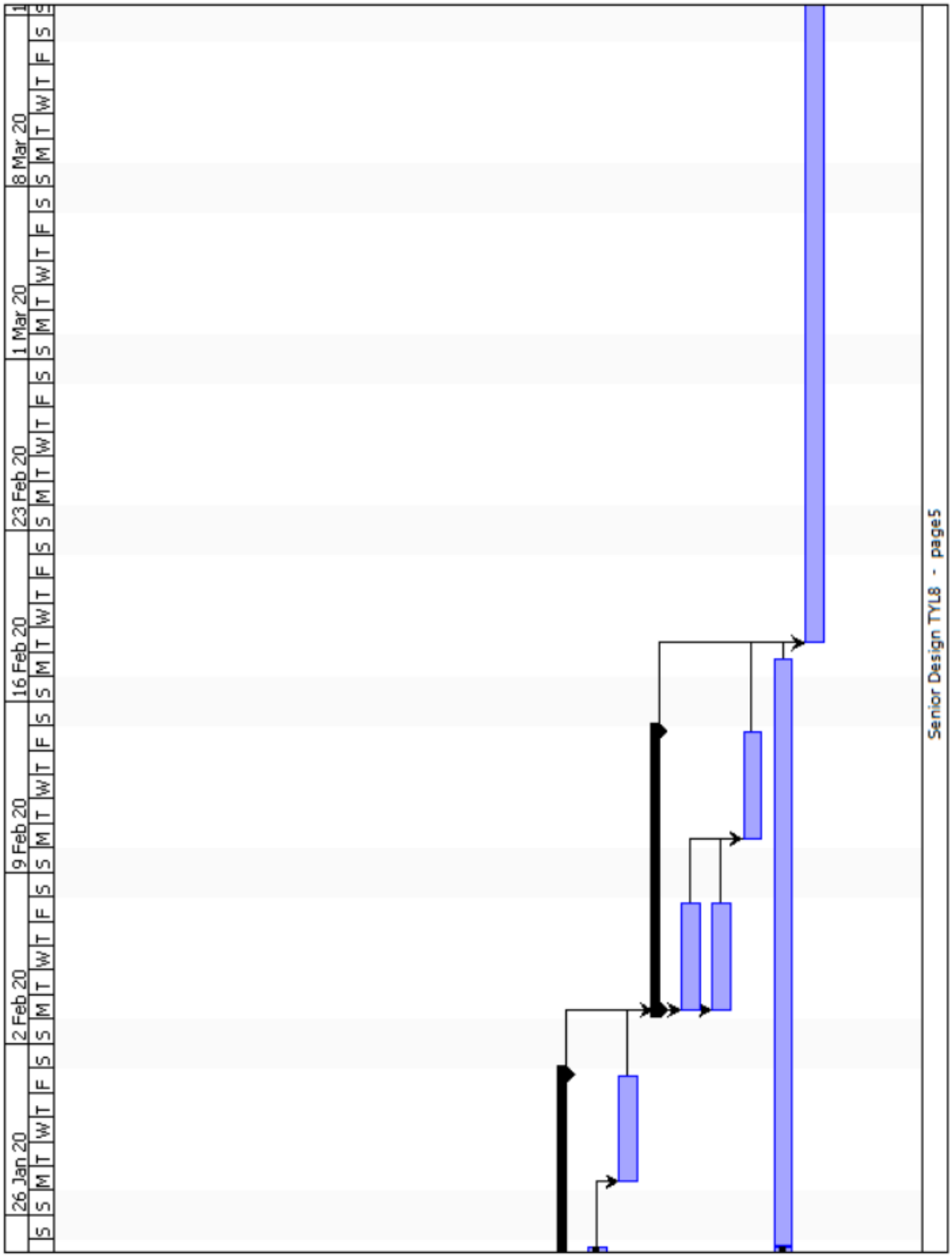


Figure B.5 Gantt Chart 4

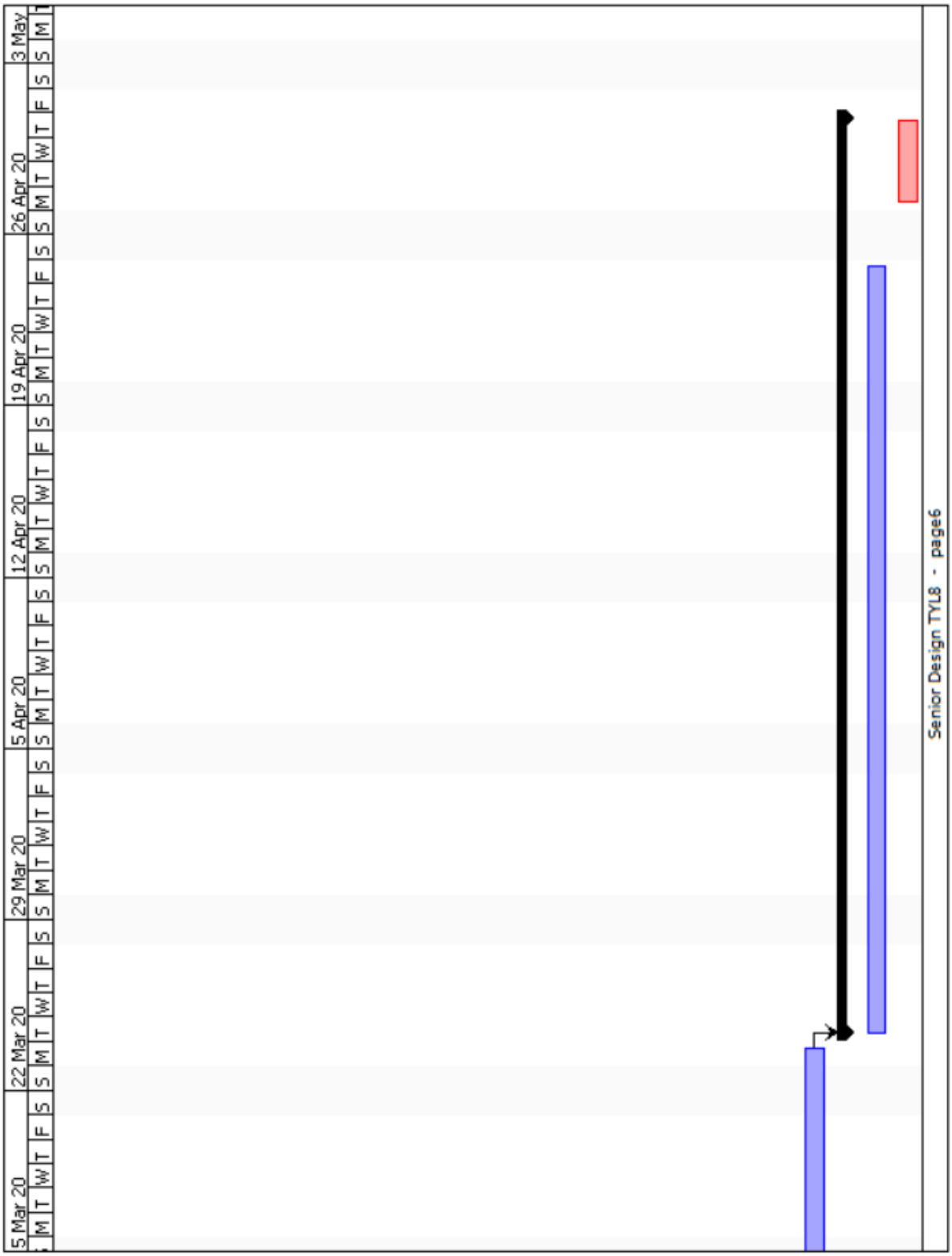


Figure B.6 Gantt Chart 5

C. Responsibility Matrix

Tasks	*Garrett Kleir*	*Tyler William*	*Breena Hughes*	*Joseph Ruesewalt*	*James Florek*	*AbdulRahman Jijak*	*Eutrope Kaptue*
Gather Specs.	C	R	A	I	I	I	I
Brainstorming	I	I	A	R	I	C	I
Idea Selection	C	I	R	I	A	I	I
Modeling	R	C	I	I	I	I	A
Tweaking	I	I	I	A	C	R	I
Sourcing	I	R	I	I	A	I	C
Model Build	I	C	A	R	I	I	I
Programming	I	C	R	A	I	I	I
Testing	A	I	I	C	R	I	I
Model Build 2	I	I	I	R	I	A	C
Testing	A	I	I	C	I	I	R
Manufacturing/Fabrications	C	I	A	R	I	I	I
Modifications as Needed and Astetic	I	I	C	I	A	R	I
Final Testing	R	I	I	I	I	C	A
Registration Setup/Manuals	C	I	I	I	I	R	A

Figure C.1 ARCI Chart

D: Mechanical Assembly Drawings

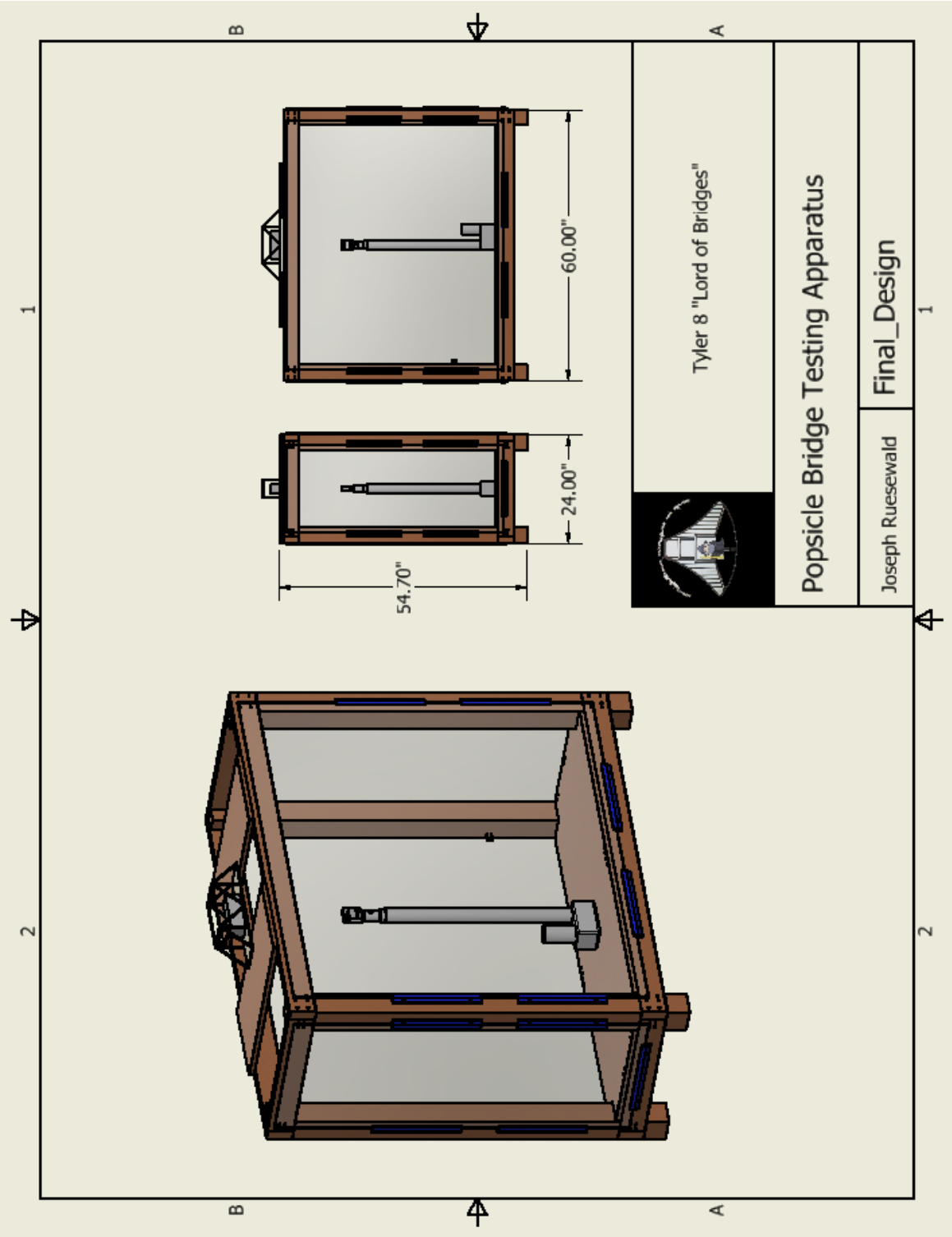


Figure D.1 Final Assembly of popsicle bridge testing apparatus

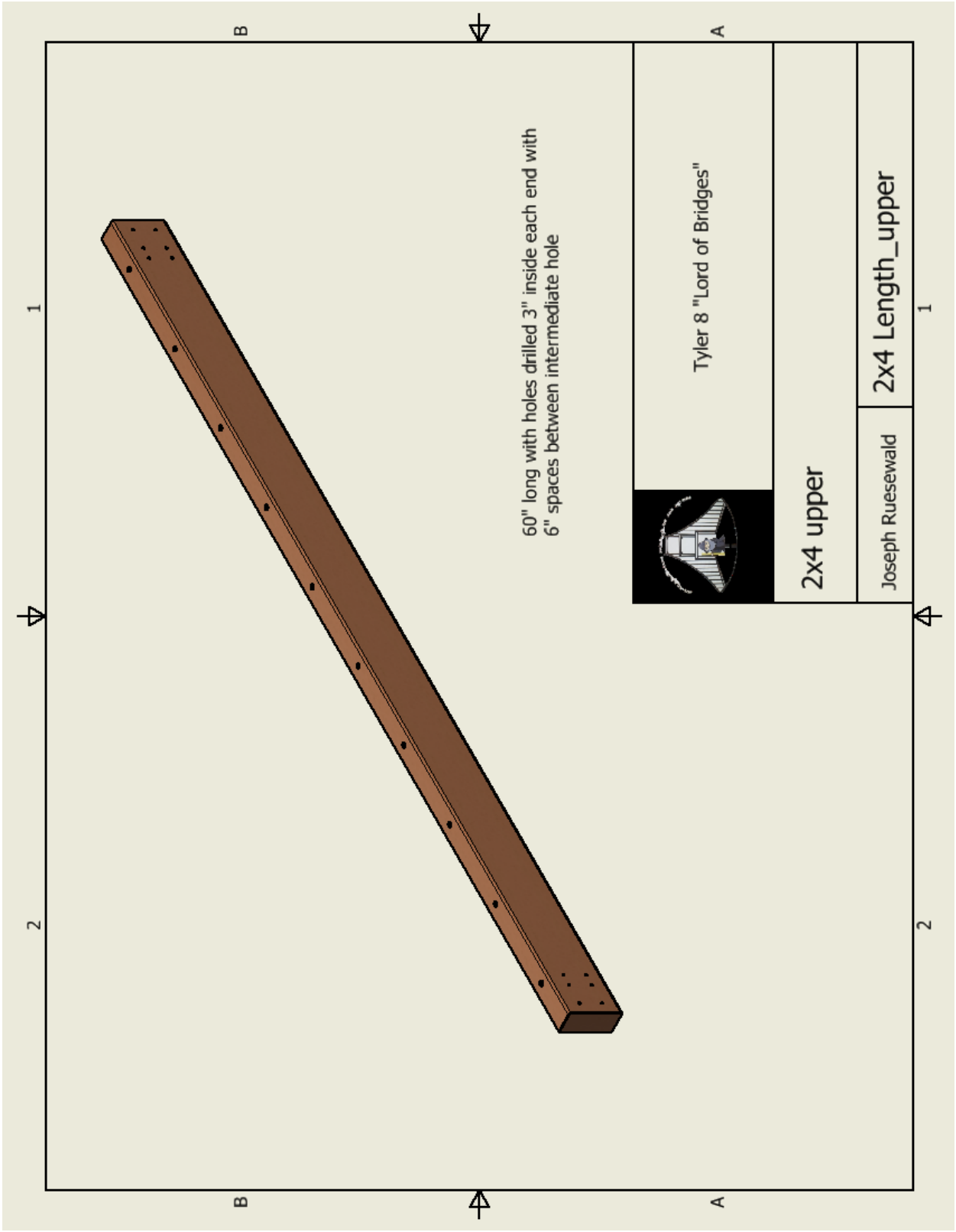


Figure D.2 Upper Lengthwise crossmember

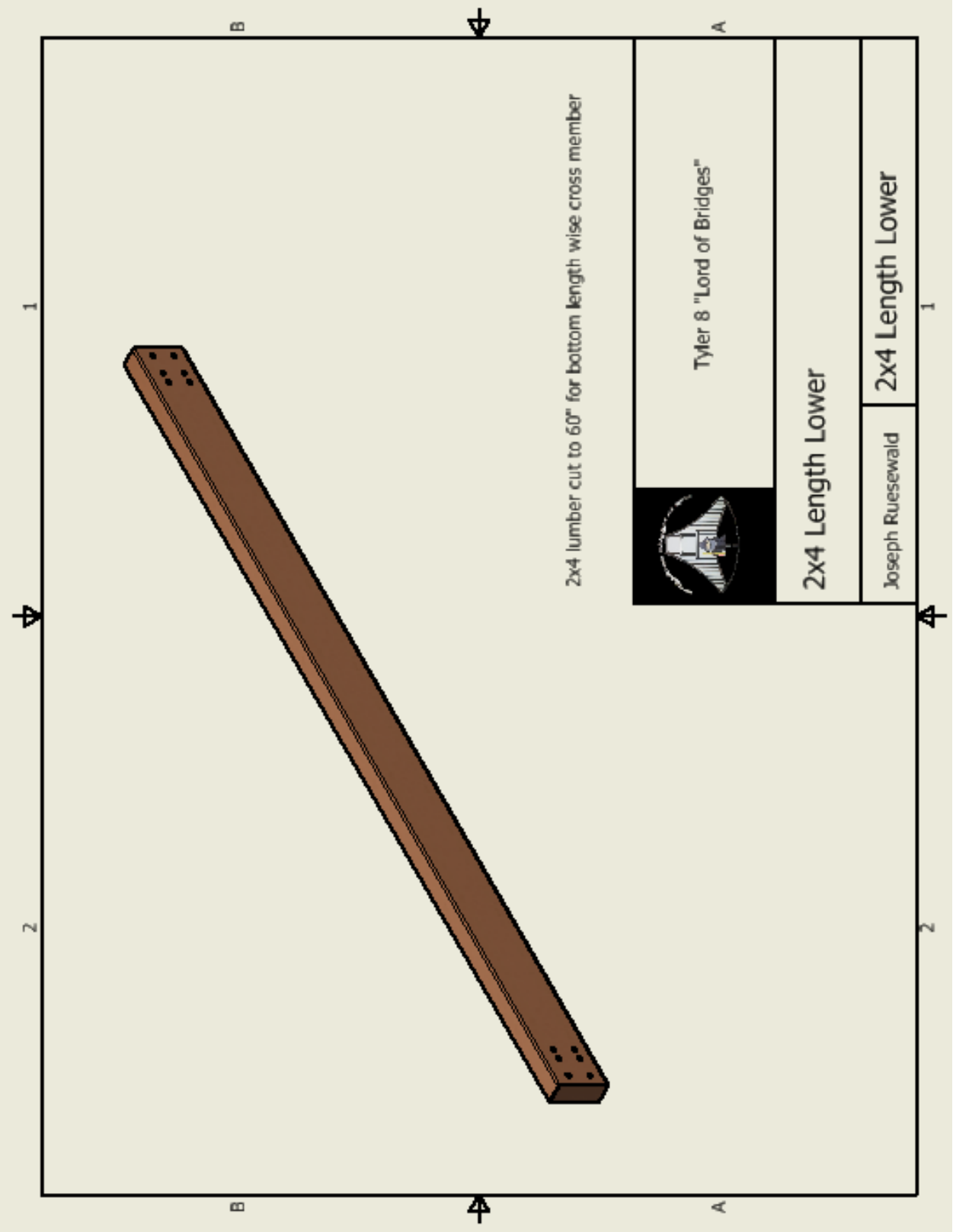


Figure D.3 Lower Lengthwise crossmember

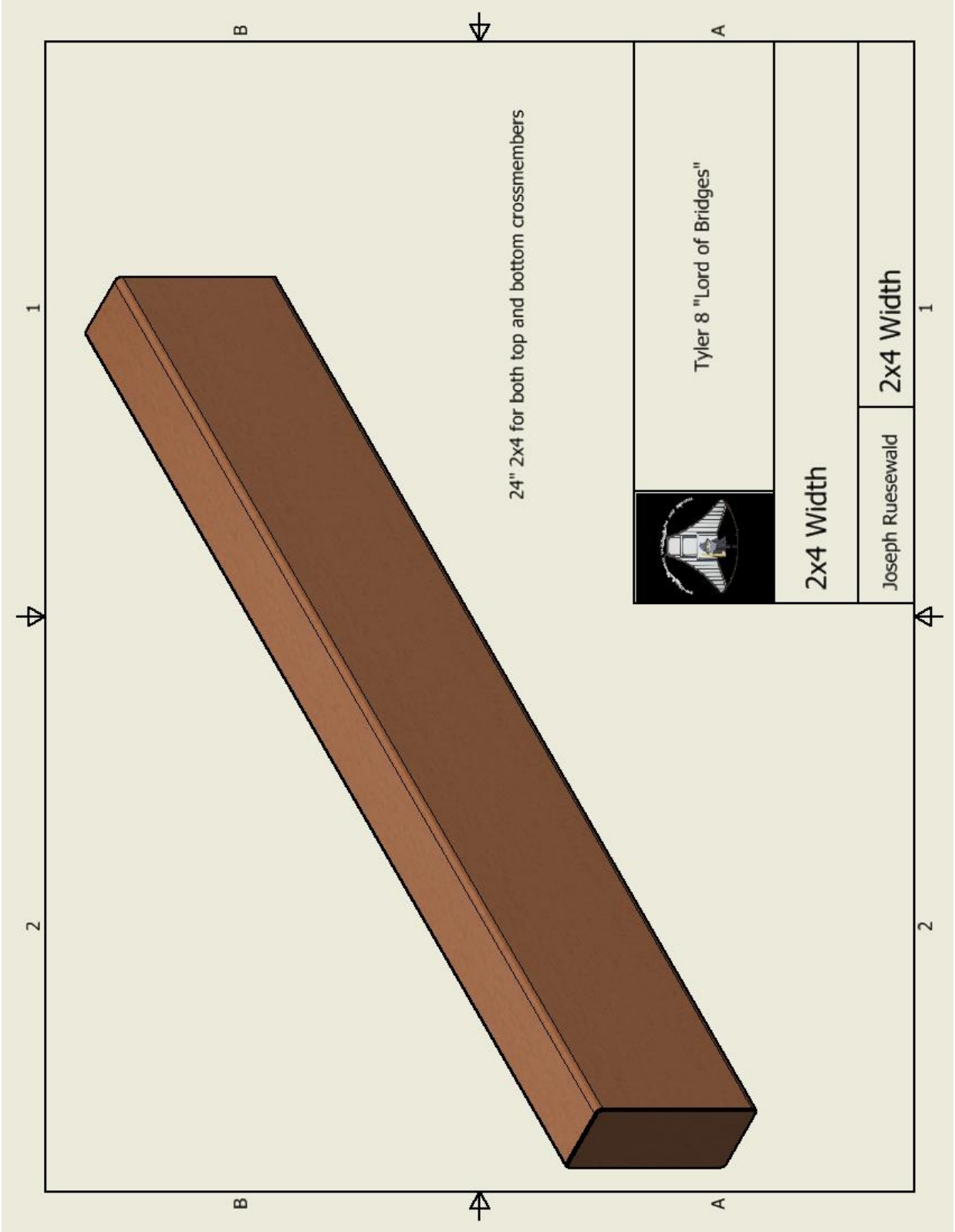


Figure D.4 Widthwise crossmember

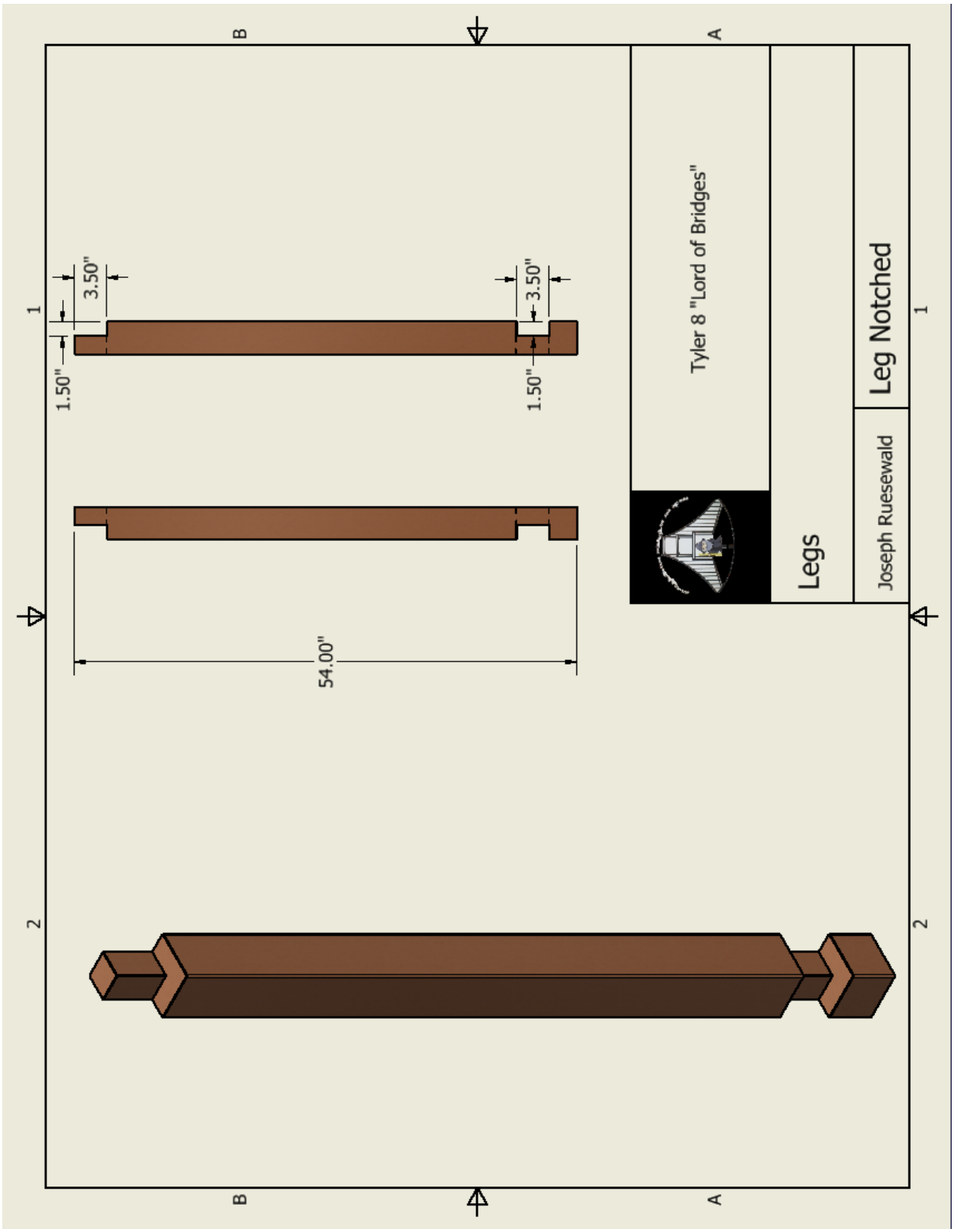


Figure D.5 Legs notched for flush mounting surface

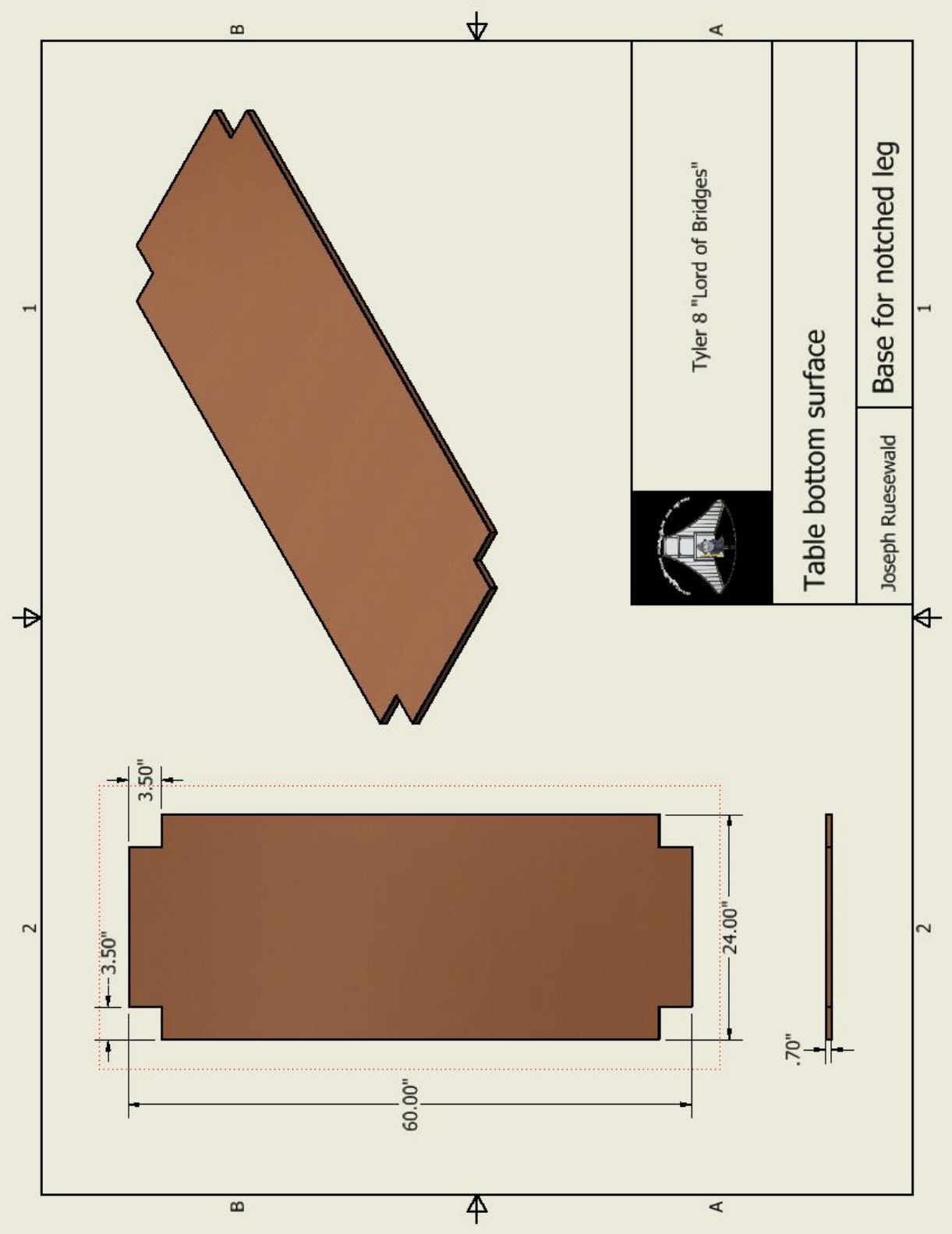


Figure D.6 Lower table surface for mounting control system and actuator

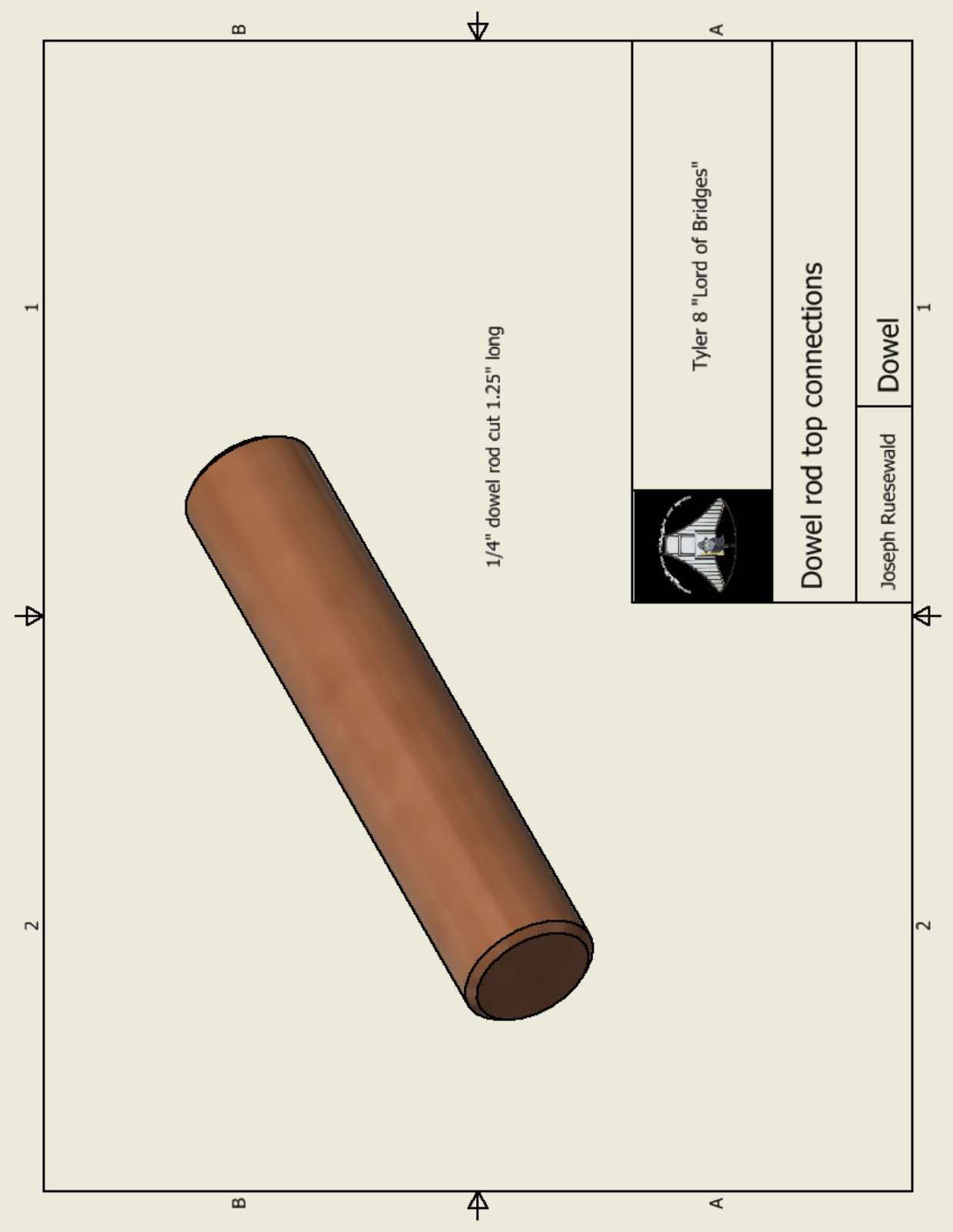


Figure D.7 Dowel rod for connecting moveable top surfaces

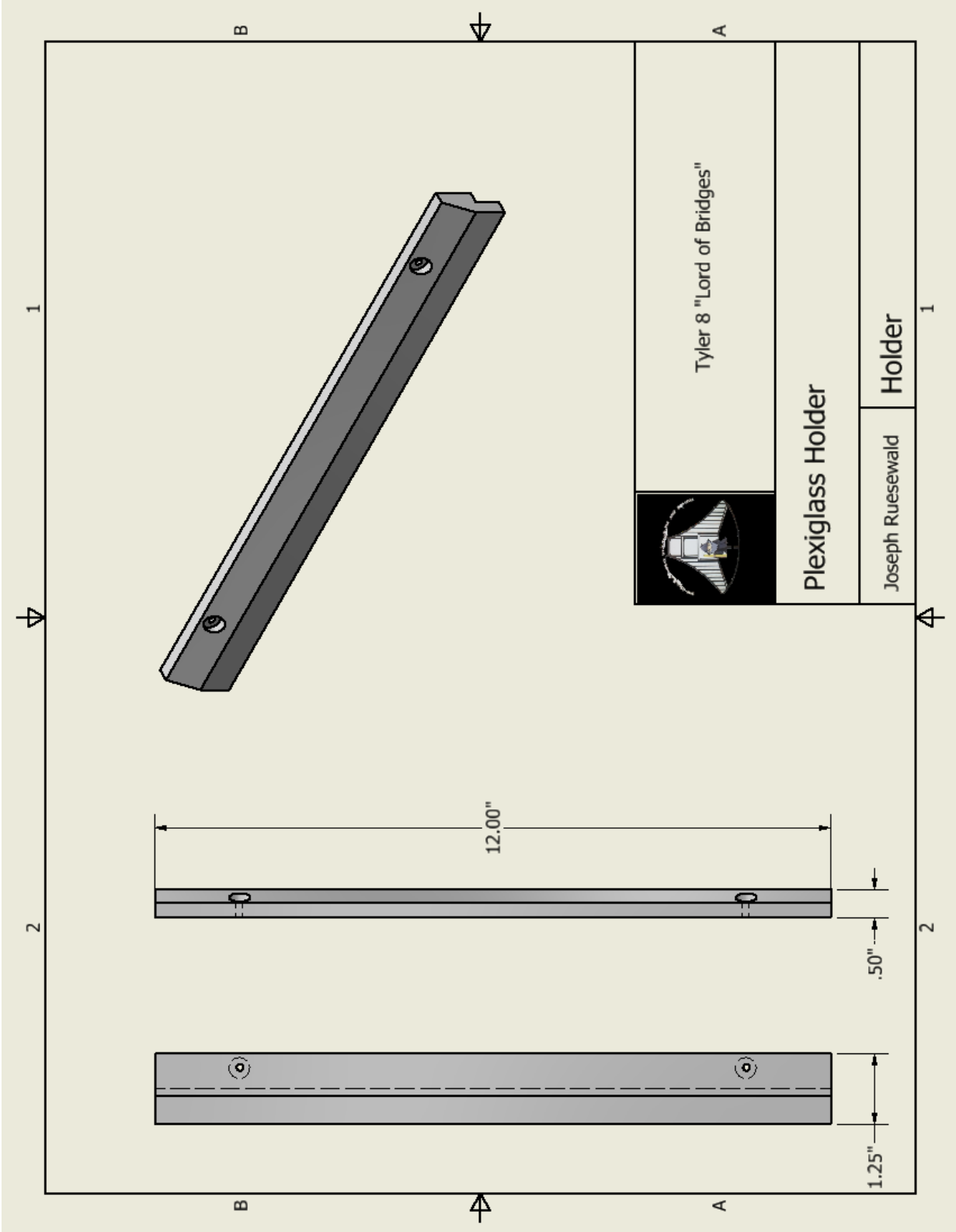


Figure D.8 Plexiglass holders to be mounted to edges of table

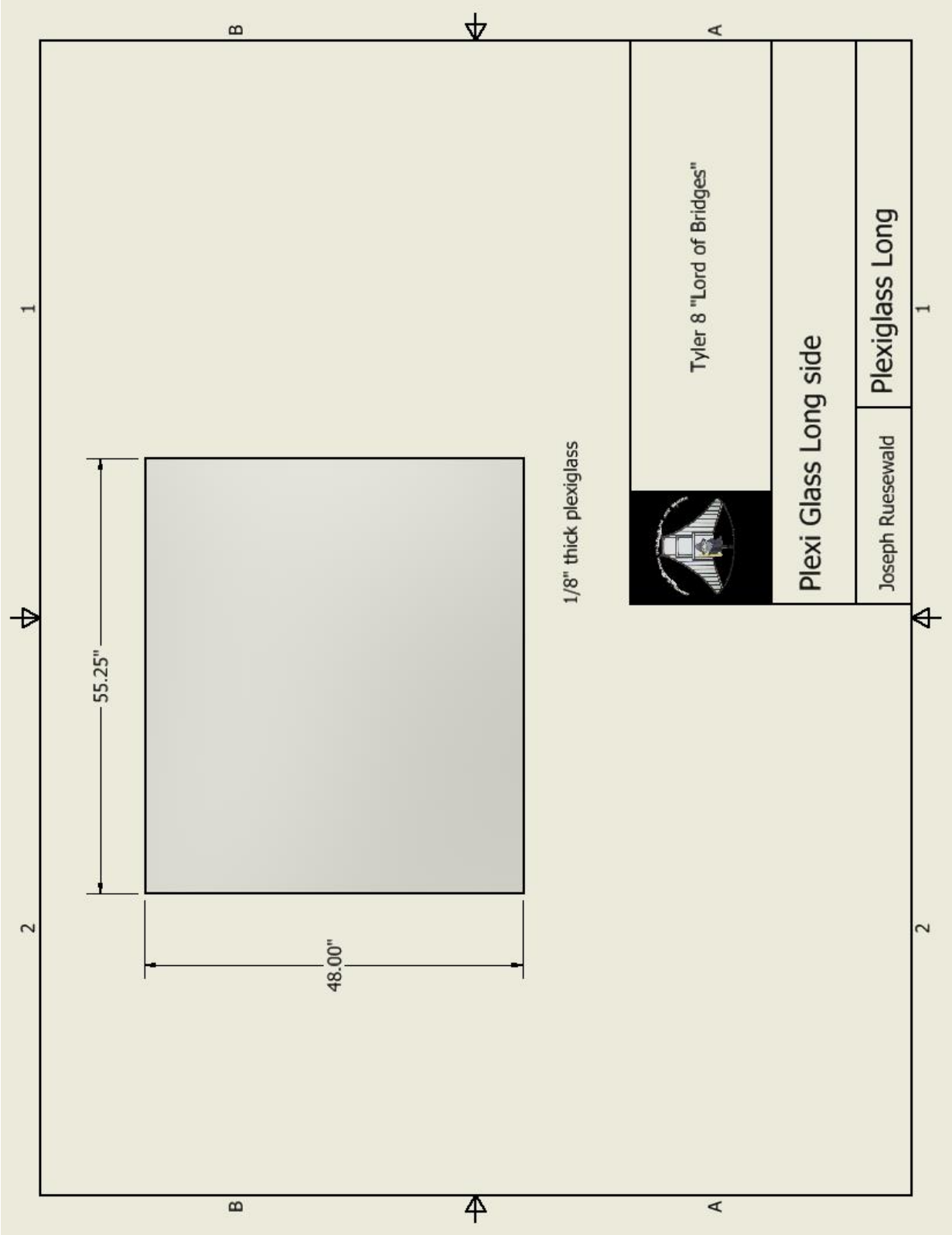


Figure D.9 Plexiglass for the Long side of the table

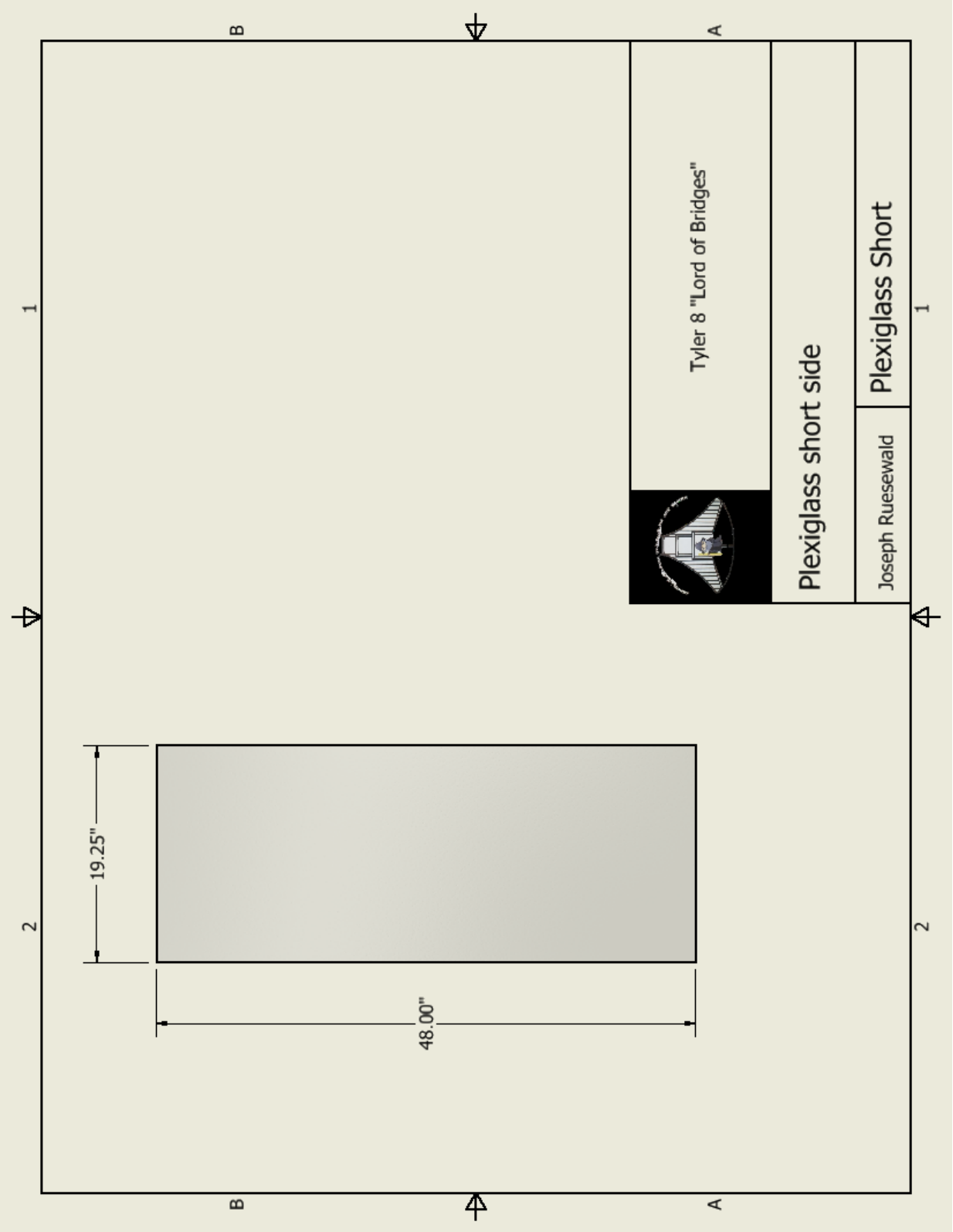


Figure D.10 Plexiglass for the short side of the table

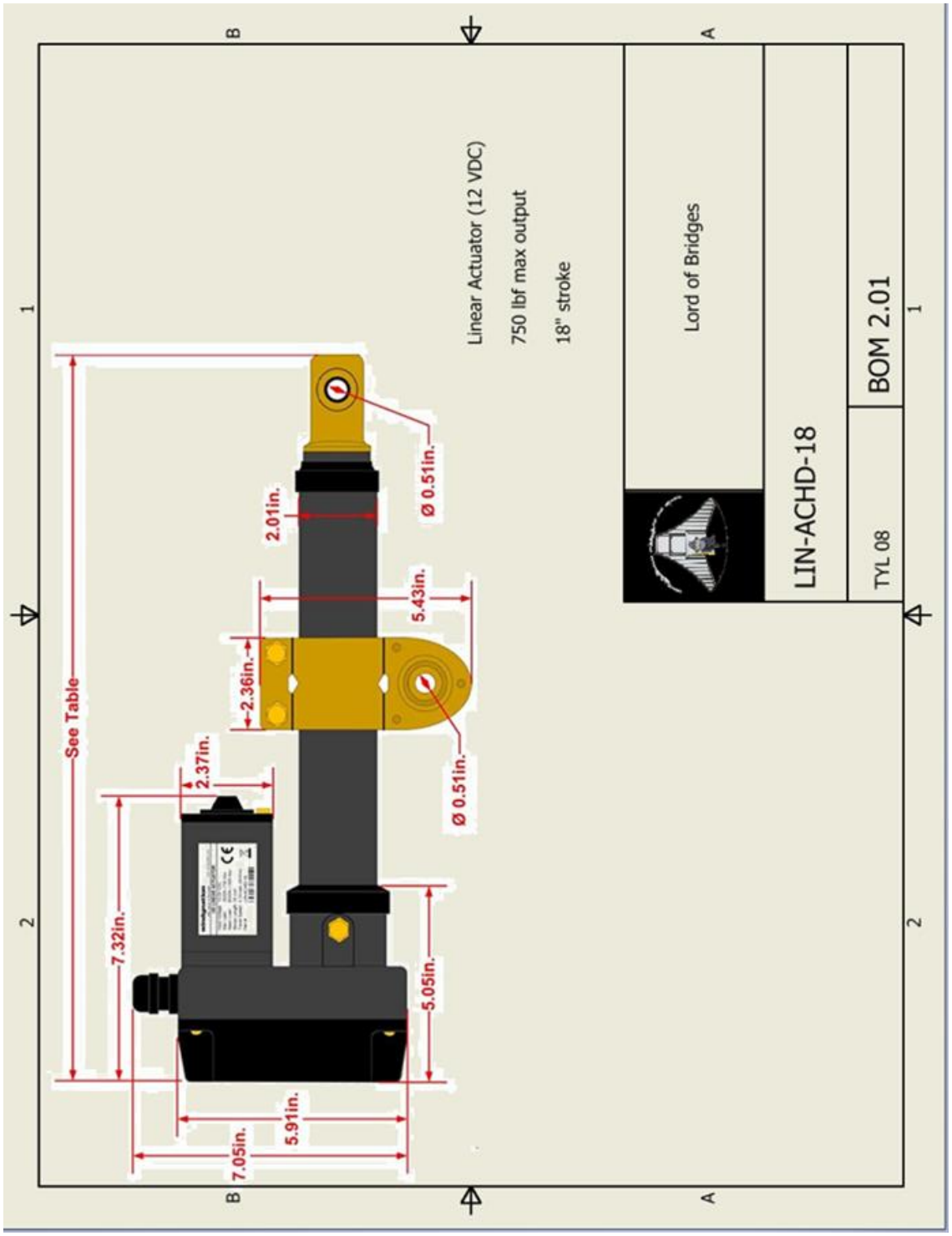


Figure D.11 LIN-ACHD-18 Linear Actuator

E. Electrical Circuits and Technical Specifications

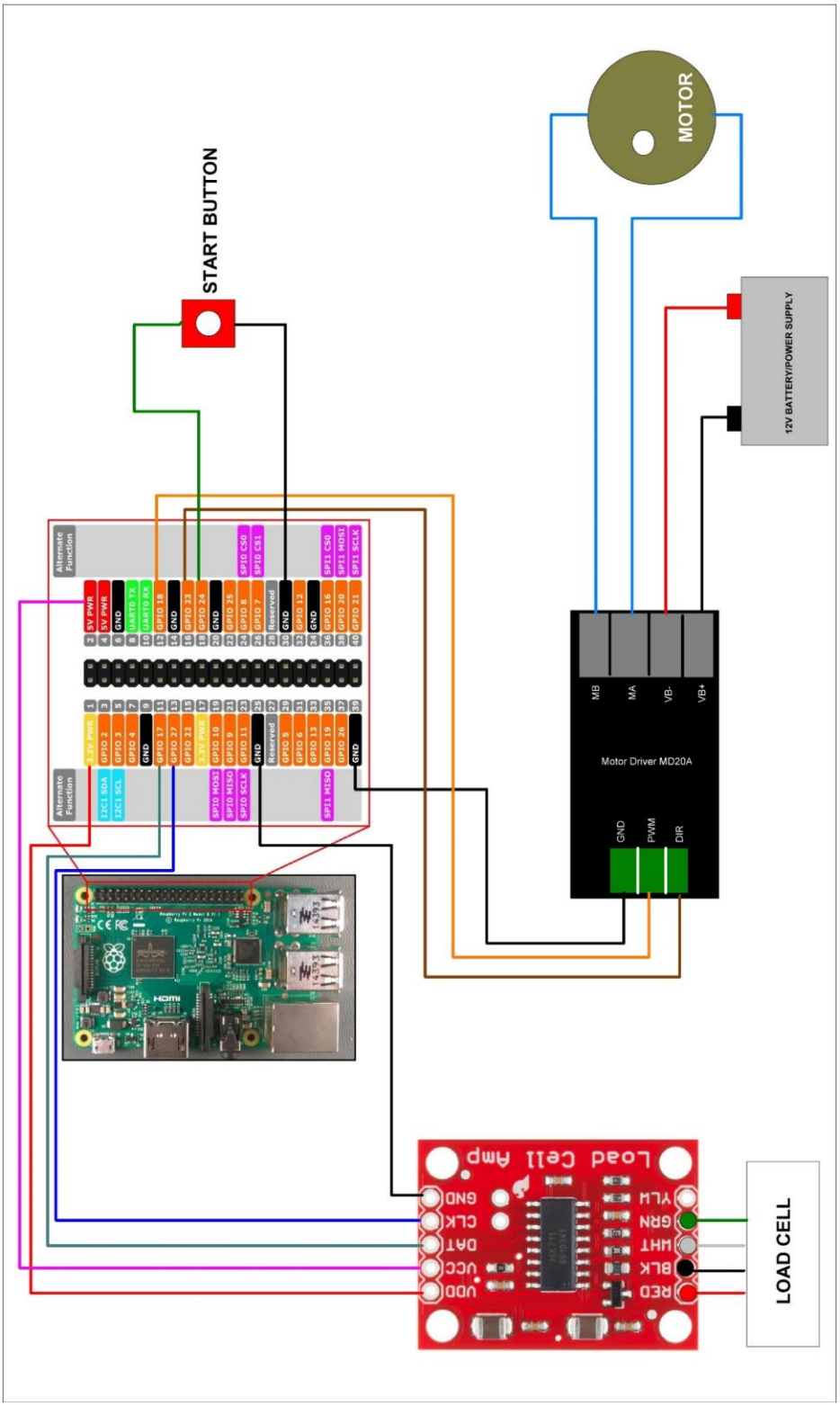


Figure E.1 System I/O and interface diagram

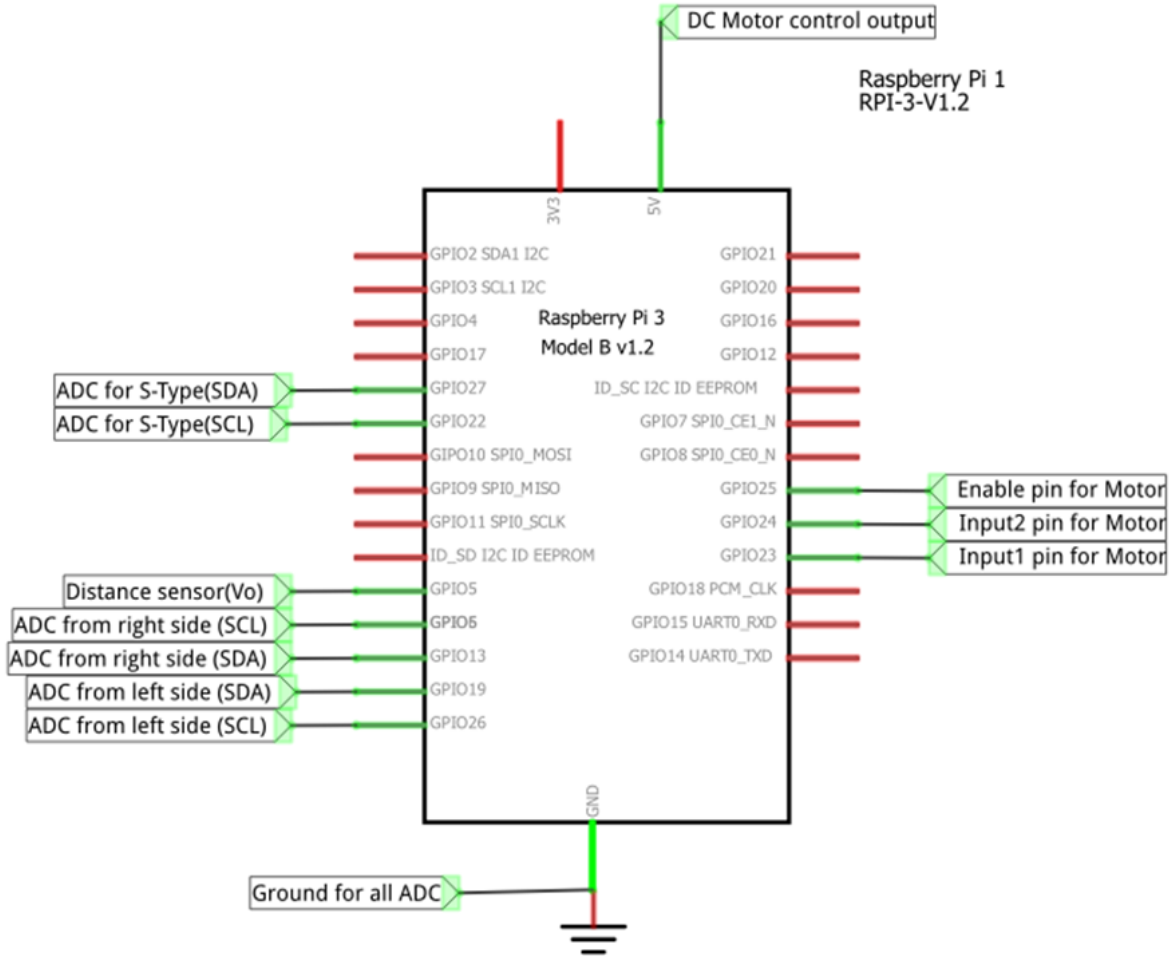


Figure E.2 Raspberry Pi 3 B+ Pin out diagram

Table E.1 LIN-ACHD 18 Specifications

Stroke Length	18”
Overall Length	30.7”
Dynamic Load	750 lbf @ 24VDC
Static Load	1500 lbf
Travel Speed (Max)	0.2 in/sec
Rated Voltage	12VDC / 24VDC
Current Draw (Max)	≤ 2.5A
Mounting Holes	0.51”

Limit Switches	Adjustable
Operational Temperature	-14.8°F to +149°F
Protection Class	IP65
Duty Cycle	20%

Table E.2 Raspberry Pi Model 3 B+ Product Specifications

Quad Core 1.2 GHz Broadcam BCM2837 64bit CPU
1 GB RAM
BCM43438 wireless LAN and Bluetooth Low Energy (BLE) on board
100 Base Ethernet
40-pin extended GPIO
4 USB 2 ports
4 Pole stereo output and composite video port
Full size HDMI
CSI camera port for connecting a Raspberry Pi camera
DSI display port for connecting a Raspberry Pi touchscreen display
Micro SD port for loading operating system and storing data
Upgraded switched Micro USB power source up to 2.5A

Table E.3 Model PSD-S1 ‘S’ type load cell specifications

Linearity	±0.02% FS
Delaying	±0.02% FS
Repeatability	±0.02% FS
Sensitivity	2.0 mV/V
Drifting	±0.02% FS
Input impedance	350±10Ω
Output impedance	350±10Ω
Measuring range	0-300 kg (0-660 lb)
Weight	575 g (1.3 lb)

F. Design Calculations

Tipping Test Calculation

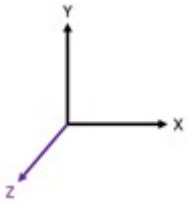
I- Methodology

1. Find the Center of Mass and Total Mass of the Object.
2. Assume tipping rather than slipping after verifying the friction coefficient.
3. Perform Moment equilibrium calculation between the Normal Force and the Push Force about the fulcrum "B" (the bottom edge opposite the applied Push Force) to find the needed Tipping Force from both sides.

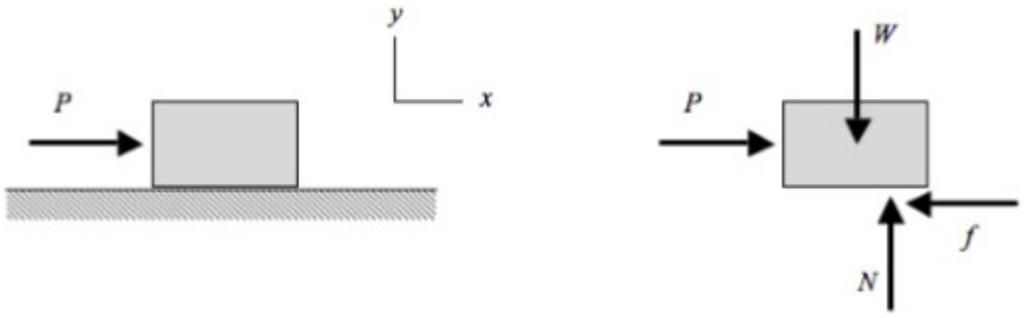
USE METRIC UNITS AND DO NECESSARY CONVERSIONS

II- Assumptions, Formulae, and Given Values:

Assumption: Orientation of Axes



Assumption: Nomenclature and Direction of Force Vectors: P=Push, W=Weight, N=Normal, f=Friction



From this FBD, we have the following equilibrium equations:

$$\sum F_x = P - f = 0 \qquad \rightarrow \qquad f = P$$

$$\sum F_y = N - W = 0 \qquad \rightarrow \qquad N = W$$

Figure F.1 Free Body diagrams and static equilibrium general equations

Table F.1 Centroids of simple areas

Shape	Area	$\bar{x}$	$\bar{y}$	
Rectangle	bh	$\frac{b}{2}$	$\frac{h}{2}$	
Triangle	$\frac{bh}{2}$	$\frac{b}{3}$	$\frac{h}{3}$	
Circle	$\frac{\pi d^2}{4}$	$\frac{d}{2}$	$\frac{d}{2}$	
Semicircle	$\frac{\pi d^2}{8}$	$\frac{d}{2}$	$\frac{4r}{3\pi}$ $(0.425r)$	
Quadrant	$\frac{\pi d^2}{16}$	$0.425r$	$0.425r$	

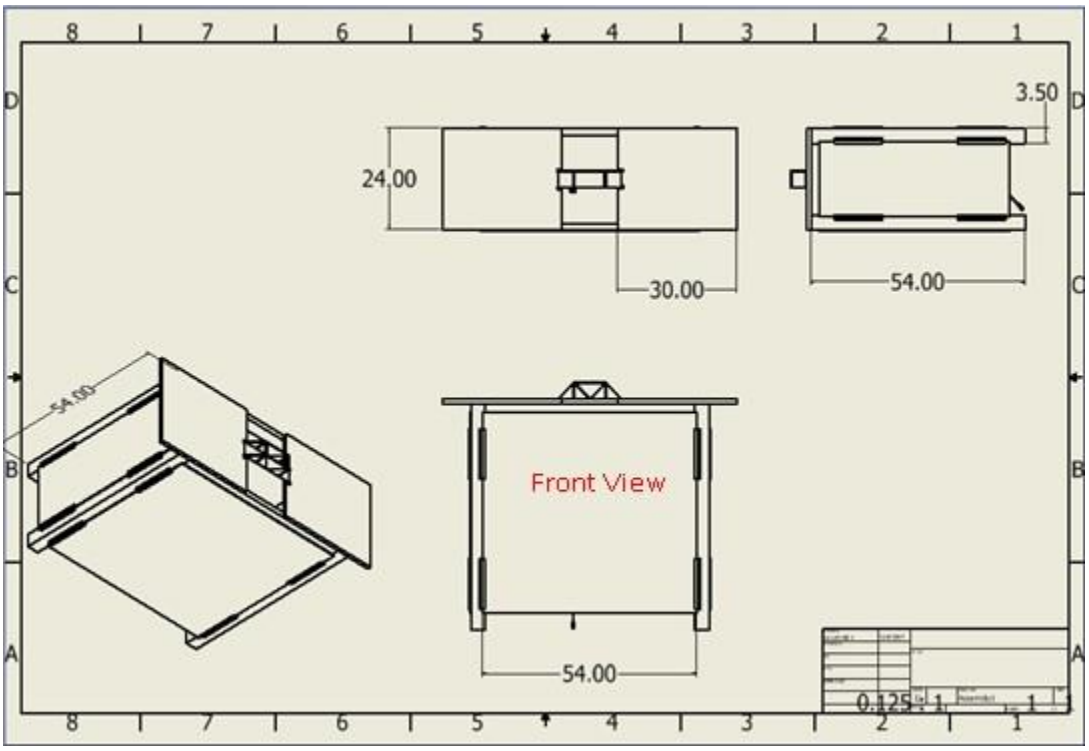


Figure F.2 Overall dimensions of table assembly

III- Diagrams and Calculations

a) Volume Calculation:

The encasement was broken down into 4 subassemblies after examining the CAD Drawing and the Bill of Material for specification. Table F.2 lists the 4 subassemblies.

Table F.2 Subassemblies used for centroidal calculations

Part	Quantity
Legs	4
Top Platform	2
Bottom Platform	1
Top base	2

Individually each piece's volume was calculated then multiplied by the quantity of each piece. The total volume of all pieces will be used to find the mass after multiplying it with the density. Using eq (1) to find total volume, eq (2) to find mass and eq (3) to find weight, the following shows the calculation procedure for finding the total weight of the table assembly.

$$V = Length * Width * Height \ldots\ldots\ldots 1$$

$$Total\ Volume = 3.06\ ft^3 = 0.08665\ m^3$$

$$Mass = Density * Total\ Volume \ldots\ldots\ldots 2$$

$$Mass = 770\ \frac{kg}{m^3} * 0.08665\ m^3 = 66.721\ kg$$

$$Weight\ =\ Mass * Acceleration\ due\ to\ Gravity \ldots\ldots\ldots 3$$

$$Weight\ =\ 66.721\ Kg\ x\ 9.81\ m/s\text{^}2\ =\ 654.53\ Newtons$$

b) Formulas and Approach to getting Centroid about Y-Axis

Note that Along both the X-Axis and Z-Axis the centroid is Midway through due to symmetry along both Axes. The Centroid along the Y-Axis is NOT necessary for the tipping Calculation from both edges of the encasement on a flat surface as will be demonstrated in the ensuing Tipping Calculations.

The Y-Axis Centroid however is necessary when uneven surfaces are considered and tipping along them needs to be calculated.

Step 1: Find the Height of centroid for each subassembly by dividing the total height by 2 since the areas are symmetrical along the Y-axis.

$$Height\ Centroid\ =\ Height/2 \ldots\ldots\ldots 4$$

Step 2: Find the Cross-Sectional surface area on the XY-plane (Front View), The YZ-plane will also work but to stay consistent with the excel sheet use XY-plane surface area.

$$Cross - Sectional\ Surface\ Area\ =\ Height *\ Length \ldots\ldots\ldots 5$$

Step 3: Find the Centroid Height along the Y-axis by translating upwards the centroid of the subassemblies that do not start at Y = 0, refer to the CAD drawing and the Bill of Material dimensions for clarification on where each piece begins and ends.

Step 4: Find the Moment of Area by multiplying the Cross-Sectional Area into the Centroid Height along the Y-Axis.

$$Moment\ of\ area\ =\ \text{Cross Sectional Area x Centroid Height} \ldots\ldots\ldots 6$$

Step 5: Divide the Total of the Moment of Area found in Step 4 by the Total of Cross Sectional Area found in Step 2.

$$(Moment\ of\ Area)/(\text{Surface Area}) =\ \text{Centroid along that axis} \ldots\ldots\ldots 7$$

$$\frac{15294.35\ in^3}{419.13\ in^2} = 36.5\ in = 0.9721\ m\ along\ Y-axis$$

(also Midway along X and Z axes)

Table F.2 shows the centroidal locations of all 3 dimensions

Table F.2 3D centroidal locations of popsicle bridge testing apparatus

Units	X-direction	Y-direction	Z-direction
in	27	36.5	12
m	0.6858	0.9721	0.3048

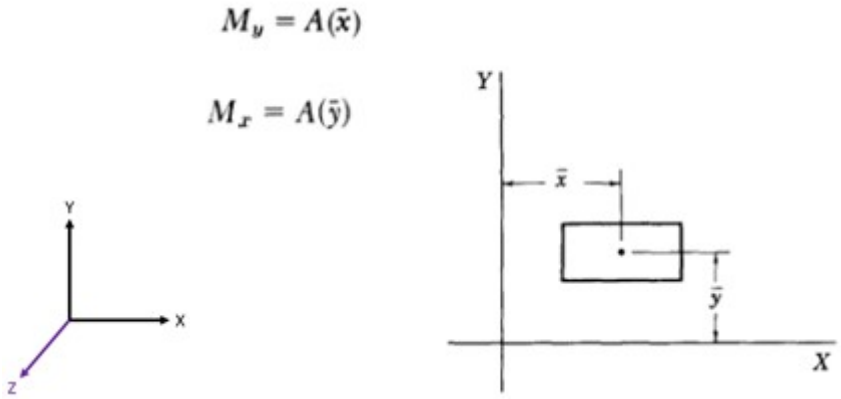


Figure F.3 Calculating moment of inertia from centroidal locations

c) Continue with the rest of the Tip or Slip Calculation, Assuming the Push Force is applied at the top most point in order to maximize the likelihood of tipping for design safety purposes.

Determine Normal force for friction force calculation to determine Tip or Slip

P= Push force, fmax = maximum friction force, μs= coefficient of static friction, N= Normal force, Note that for this case N = -Weight

$$mass \ = \ 147.10 \, lb \ = \ 66.7 \, Kg$$

$$Weight \ = (66.7Kg) \, x \, (-9.8 \frac{m}{s^2}) \ = \ -653.66 \, Newtons$$

$$N \ = \ 653.66 \, Newtons$$

$\mu s \ = \ 0.62$ (Wood On Concrete Clean Dry [4])

$$P \ > \ \text{fmax} \ = \ \mu s \text{N} \ldots \ldots \ldots 8$$

The Push force needs to be greater than the maximum friction force to tip the encasement. We will conduct moment about point B equilibrium to find the maximum Push Force at which the object will not Tip. Two sides will be considered, the longer and the shorter side.

Case 1: Push onto the Longer Side (less force required to tip)

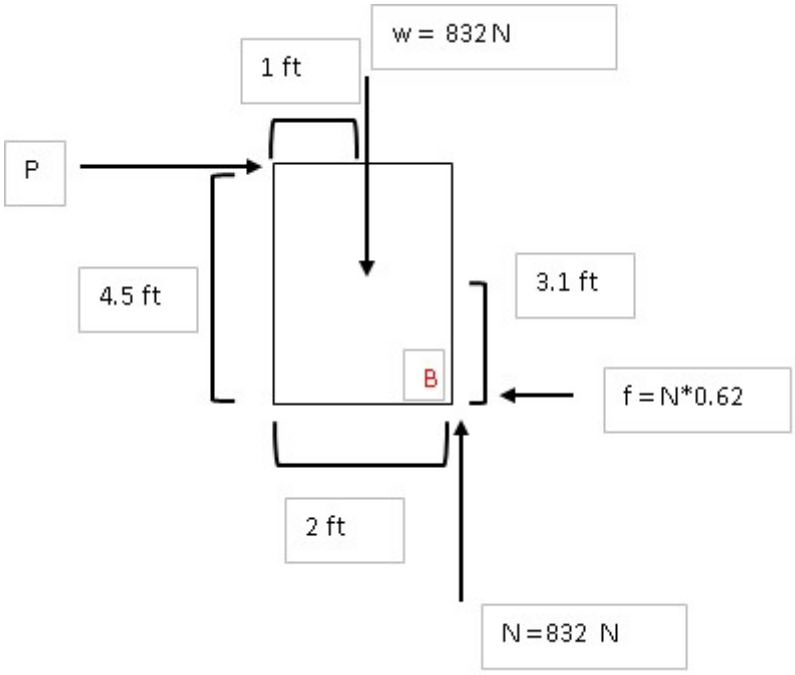


Figure F.3 Tipping force observation on longer side of table assembly

Add the Normal force resulting from any additional weight of components added to the encasement to xtra:

$$xtra = 178\ N$$

$$N = 654\ N + xtra$$

N= Final Normal force after adding all addition weight

(An assumption of all additional weight to be acting on the same center of mass is made for simplicity since most of the weight will be from the encasement and the actuator which is anyways located at the center)

Moment Equilibrium about point B

Firstly verify that it will tip rather than slip:

Force needed to Slip:

fmax = μsN

$\mu s := 0.62$

$N = 832\ N$

$fmax := \mu s \cdot N$

$fmax = 515.84\ N$

Extra weight:
0.5"x1'x1' steel plate of density
0.284lb/in^3 [9]
72in^3 x 0.284lb/in^3
=20lb
also 20 lb for Actuator
brings total of xtra to 40lb
which is 178N

Force needed to Tip, refer to diagram above and use Moment Equilibirum about B:
clockwise moment = counterclockwise moment

4.5P = 1W

P = W/4.5

$W := 832\ N$

$P := \frac{W}{4.5}$

$P = 184.889\ N$

Figure F.4 MathCad Calculations for tipping force applied to longer side of table assembly

Case 2: Push onto the Shorter Side (More force required to tip)

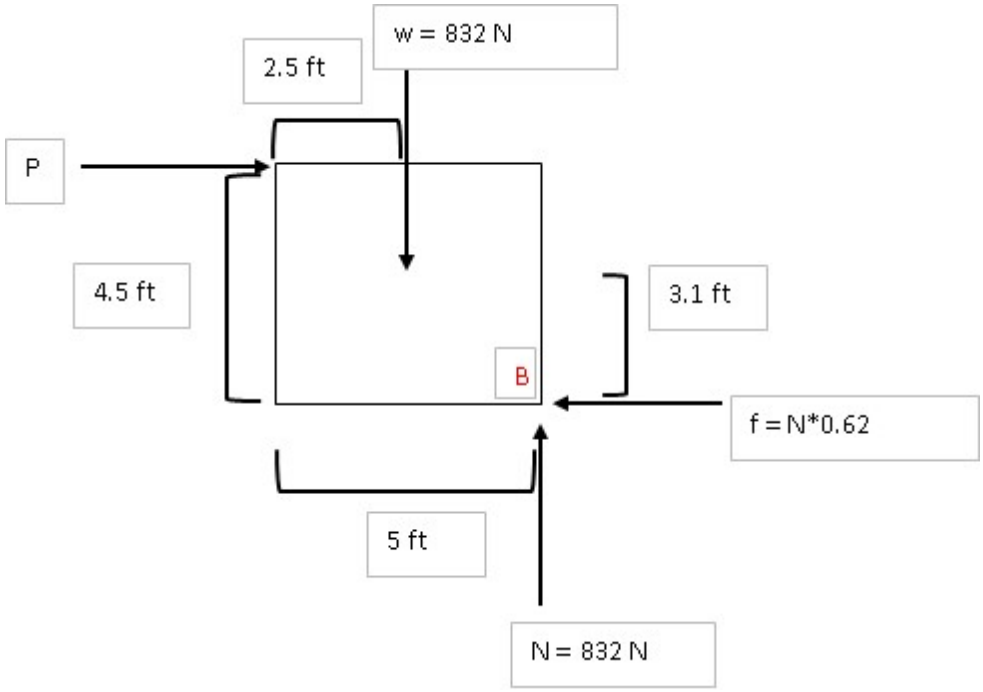


Figure F.5 Tipping force observation on shorter side of table assembly

Moment Equilibrium about point B

Firstly verify that it will tip rather than slip:

Force needed to Slip:

fmax = μsN

$\mu s := 0.62$

$N = 832\ N$

$fmax := \mu s \cdot N$

$fmax = 515.84\ N$

Force needed to Tip, refer to diagram above and use Moment Equilibirum about B:
clockwise moment = counterclockwise moment

4.5P = 2.5W

P = 5W/9

$W := 832\ N$ $\qquad P := \frac{5\ W}{9}$ $\qquad P = 462.222\ N$

Figure F.6 MathCad calculations for tipping force applied to shorter side of table assembly

IV- Suggestions for added stability

After adding the Actuator's and steel plate's weight of a total of 40 lbs, the new and old values are as follows:

CASE RESULTS: Old/New

1(push along long side) 145 N (15Kg) /185 N (19Kg)

2(push along short side) 363 N (37Kg)/462 N (47Kg)

In Case 1 which is the most prone to tipping, P has a 4.5 times mechanical advantage compared to the weight since P acts at a length of 4.5 ft from the fulcrum while the weight has a length of only 1 ft from the fulcrum.

A better solution to increasing the weight at a 4.5 times disadvantage is to instead increase the length of the moment arm of the weight from the fulcrum. A convenient approach is to simply add 1-foot long legs at the fulcrum, hence increasing the moment arm length to 2, thereby double the needed force to tip from 19Kg equivalent to 38Kg equivalent, or even better, by adding 2-foot long feet at the 4 corners of the encasement, which in turn would make the minimum force needed to tip 19x3 so 57Kg equivalent which is quite sufficient. These feet can be either attached by simply screwing them in there permanently, which is not as recommended as the second approach.

The second approach to attaching the feet is to instead continue with the theme of employing carpentry techniques to create 1 slot per leg of the encasement where detachable legs can be installed while in storage or in operation, and when the Encasement needs to be moved around, those 4 legs can be removed temporarily to facilitate transport.

A Third quick fix is to simply have 4 bags of sand, some 10 lbs. each at the 4 legs which while it does the job, is an eye sore and unprofessional.

G. Experimental procedures and Results

Table G.1: Testing iterations for calibrating the ‘S’ Type sensor

Load (lbf)	Sensor Voltage (mV)
0	0
13.2875	0.15
17.3	0.2
20.6625	0.3
26.8875	0.35
32.0875	0.45
41.2375	0.6
32.0875	0.45
26.8875	0.35
20.6625	0.3
17.3	0.2
13.2875	0.15
0	0

Table G.2: Final simulation testing data of popsicle bridge testing apparatus

Iteration	Test 1	Test 2	Test 3
1	1 lbf	0 lbf	0 lbf
2	1 lbf	1 lbf	1 lbf
3	1 lbf	16 lbf	19 lbf
4	8 lbf	25 lbf	30 lbf
5	37 lbf	44 lbf	59 lbf
6	254 lbf	101 lbf	136 lbf

H. Program Coding

```
#! /usr/bin/python2

#------------------------------Start Code Excel ----------------------------------------------------
import xlsxwriter
#=======================================
import openpyxl
from openpyxl.styles import Alignment
#=======================================
import os
import os.path
from os import path
import json
import glob
import sys


# #sudo apt-get install python-openpyxl
# #sudo apt-get install python3-openpyxl

filename= 'test.xlsx'
x = path.exists(filename)

if x == False:
    workbook = xlsxwriter.Workbook(filename)
    worksheet = workbook.add_worksheet()

    # Write Data to Excel
    cell_format = workbook.add_format()
    cell_format.set_align('vcenter')
    cell_format.set_align('center')
    cell_format.set_font_color('black')
    workbook.close()

# data = openpyxl.load_workbook(filename)
# Sheet = data['Sheet1']
#
alignment=Alignment(horizontal='general',vertical='bottom',text_rotation=0,wrap_text=False,shr
ink_to_fit=False,indent=0)
#------------------------------End Code Excel ----------------------------------------------------
```

```
#-------------------------------Start Code MoveMotor ----------------------------------------------------
import RPi.GPIO as GPIO
from time import sleep
start=24
motor=18
direction=23
up=4
down=12

GPIO.setwarnings(False)
GPIO.setmode(GPIO.BCM)
GPIO.setup(direction,GPIO.OUT)  # All pins as Outputs
GPIO.setup(start,GPIO.IN,pull_up_down=GPIO.PUD_UP)
GPIO.setup(up,GPIO.IN, pull_up_down=GPIO.PUD_UP)
GPIO.setup(down,GPIO.IN, pull_up_down=GPIO.PUD_UP)
GPIO.setup(motor,GPIO.OUT)
pwm=GPIO.PWM(motor,70) # configuring Enable pin for PWM
FiveValues = []
GPIOState = GPIO.LOW
mylist =[]

pwm.start(0)
def setup():
   GPIO.setmode(GPIO.BCM)             # GPIO Numbering
   GPIO.setup(direction,GPIO.OUT)  # All pins as Outputs
   # GPIO.output(motor,GPIO.HIGH)


def destroy():
   # GPIO.output(standby,GPIO.LOW)
   pwm.ChangeDutyCycle(0)
   GPIO.cleanup()

# if __name__ == '__main__':     # Program start from here
#     setup()
#     try:
#         loop()
#     except KeyboardInterrupt:
#         # GPIO.output(Motor1A,GPIO.LOW)
#         # GPIO.output(Motor1B,GPIO.LOW)
#
#         destroy()
```

```
#------------------------------End Code MoveMotor ----------------------------------------------------


import time
import sys

EMULATE_HX711=False

referenceUnit = 1

if not EMULATE_HX711:
    import RPi.GPIO as GPIO
    from hx711 import HX711
else:
    from emulated_hx711 import HX711

def cleanAndExit():
    print("Cleaning...")

    if not EMULATE_HX711:
        GPIO.cleanup()

    print("Bye!")
    sys.exit()

hx = HX711(17, 27)

# I've found out that, for some reason, the order of the bytes is not always the same between versions of python, numpy and the hx711 itself.
# Still need to figure out why does it change.
# If you're experiencing super random values, change these values to MSB or LSB until to get more stable values.
# There is some code below to debug and log the order of the bits and the bytes.
# The first parameter is the order in which the bytes are used to build the "long" value.
# The second paramter is the order of the bits inside each byte.
# According to the HX711 Datasheet, the second parameter is MSB so you shouldn't need to modify it.
hx.set_reading_format("MSB", "MSB")

# HOW TO CALCULATE THE REFFERENCE UNIT
# To set the reference unit to 1. Put 1kg on your sensor or anything you have and know exactly how much it weights.
# In this case, 92 is 1 gram because, with 1 as a reference unit I got numbers near 0 without any weight
# and I got numbers around 184000 when I added 2kg. So, according to the rule of thirds:
```

```
# If 2000 grams is 184000 then 1000 grams is 184000 / 2000 = 92.
#hx.set_reference_unit(113)
hx.set_reference_unit(14.9)

hx.reset()

hx.tare()

print("Tare done! Add weight now...")

# to use both channels, you'll need to tare them both
#hx.tare_A()
#hx.tare_B()


def Processing(mylist):
    global Sheet
    global pwm
    global direction
    global GPIO
    global GPIOState

    IsSmallerThanLargest = False
    runner = 0
    for i, record in enumerate(mylist):
        if (i+5)<= len(mylist) - 1:
            #print("current : "+str(record))
            if record > mylist[i+1] and record > mylist[i+2] and record > mylist[i+3] and record >
mylist[i+4]:

                IsSmallerThanLargest = True

                data = openpyxl.load_workbook(filename)
                Sheet = data['Sheet1']

alignment=Alignment(horizontal='general',vertical='bottom',text_rotation=0,wrap_text=False,shr
ink_to_fit=False,indent=0)
                #runner = Sheet.max_row + 1
                #print (" Runner=======> " + str(runner))

                #print(str(mylist[i])+"==>" + str(mylist[i+1])+" " + str(mylist[i+2])+" " +
str(mylist[i+3])+" " + str(mylist[i+4])+" " + str(mylist[i+5]))
                Sheet.cell(row=i+1+runner, column=1).value = record
                Sheet.cell(row=i+1+runner, column=1).alignment = Alignment(horizontal="center",
vertical="center")
```

```
            Sheet.cell(row=i+2+runner, column=1).value = mylist[i+1]
            Sheet.cell(row=i+2+runner, column=1).alignment = Alignment(horizontal="center",
vertical="center")

            Sheet.cell(row=i+3+runner, column=1).value = mylist[i+2]
            Sheet.cell(row=i+3+runner, column=1).alignment = Alignment(horizontal="center",
vertical="center")

            Sheet.cell(row=i+4+runner, column=1).value = mylist[i+3]
            Sheet.cell(row=i+4+runner, column=1).alignment = Alignment(horizontal="center",
vertical="center")

            Sheet.cell(row=i+5+runner, column=1).value = mylist[i+4]
            Sheet.cell(row=i+5+runner, column=1).alignment = Alignment(horizontal="center",
vertical="center")

            Sheet.cell(row=i+6+runner, column=1).value = mylist[i+5]
            Sheet.cell(row=i+6+runner, column=1).alignment = Alignment(horizontal="center",
vertical="center")
            #runner+= 1


            data.save(filename)
    global FiveValues
    FiveValues = []
    if IsSmallerThanLargest == False:
        if GPIOState == 0:
            GPIOState = GPIO.HIGH
            print("Current GPIO is: " + str(GPIOState))
        elif GPIOState == 1:
            GPIOState = GPIO.LOW
            print("Current GPIO is: " + str(GPIOState))

        print("Stopping")
        pwm.ChangeDutyCycle(0)
        sleep(5)


        pwm.ChangeDutyCycle(100)
        GPIO.output(direction, GPIOState)
        print("GOing reverse ")
        sleep(5)


while True:
```

```
try:
    """ manule control mode """
    while(GPIO.input(up) == GPIO.LOW):
        GPIO.output(direction, GPIO.HIGH)
        print("move up")
        pwm.ChangeDutyCycle(100)

    while(GPIO.input(down) == GPIO.LOW):
        pwm.ChangeDutyCycle(100)
        GPIO.output(direction, GPIO.LOW)
        print("move down")


    print("motor stop")
    pwm.ChangeDutyCycle(0)


    """ automatic control mode """
    if(GPIO.input(start) ==GPIO.LOW):
        while(True):

            if(GPIO.input(down) == GPIO.LOW or GPIO.input(up) == GPIO.LOW):
                print("back to manule mode ")
                break

            print("start ready")
        # Going forwards

            GPIO.output(direction, GPIOState)
            pwm.ChangeDutyCycle(100)
            sleep(5)

             # Prints the weight. Comment if you're debbuging the MSB and LSB issue.
            val = hx.get_weight(5)
            #print(val)

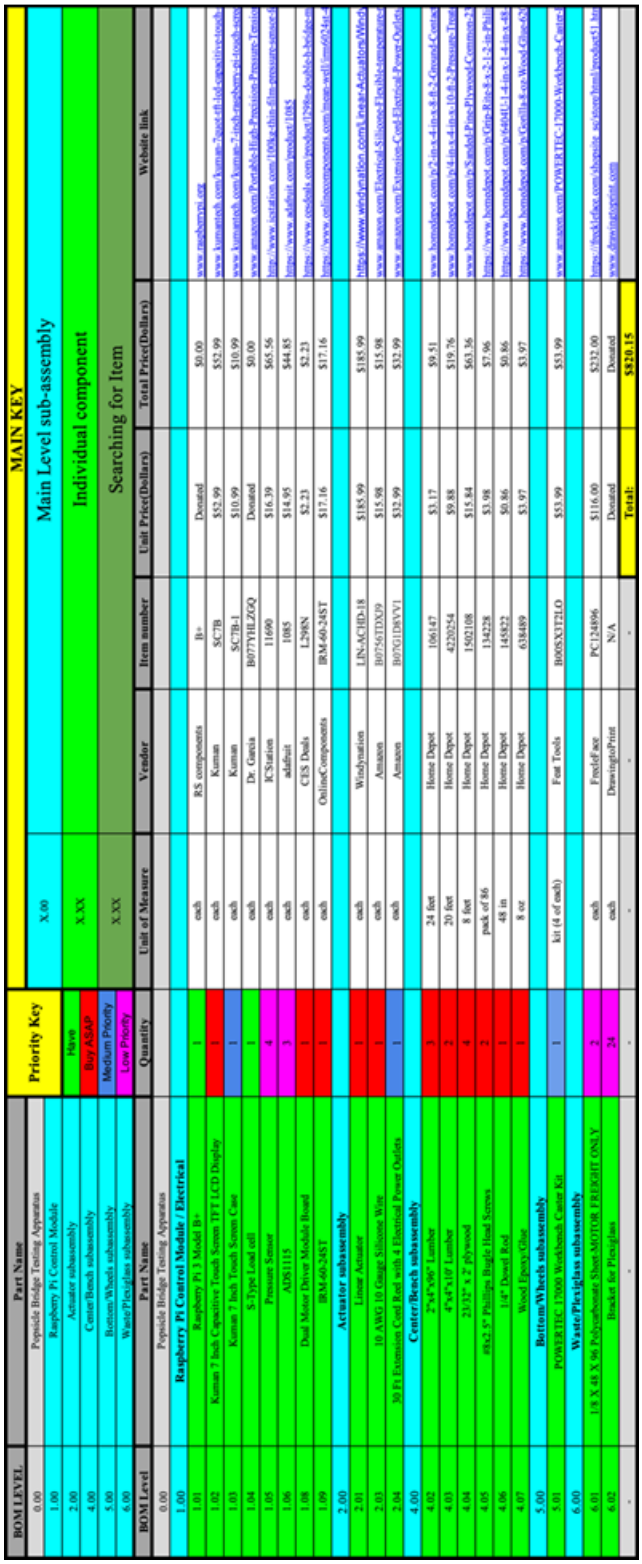
            #print("length "+ str(len(FiveValues)))
            if len(FiveValues) < 7:
                FiveValues.append(int(val))
                #print("value added")

            if len(FiveValues) == 6:
                print(FiveValues)
                Processing(FiveValues)
```

```
            hx.power_down()
            hx.power_up()
            time.sleep(0.1)

except (KeyboardInterrupt, SystemExit):
    cleanAndExit()
```

I. Cost Analysis



BOM LEVEL	Part Name	Priority Key	MAIN KEY					
0.00	Popsicle Bridge Testing Apparatus	Have	X.00	Main Level sub-assembly				
1.00	Raspberry Pi Control Module	Buy ASAP	XX	Individual component				
2.00	Actuator subassembly	Medium Priority	XXX	Searching for Item				
4.00	CenterBench subassembly	Low Priority						
5.00	Bottom Wheels subassembly							
6.00	Waste Plexiglass subassembly							

BOM Level	Part Name	Quantity	Unit of Measure	Vendor	Item number	Unit Price(Dollars)	Total Price(Dollars)	Website link
0.00	Popsicle Bridge Testing Apparatus							
1.00	**Raspberry Pi Control Module / Electrical**							
1.01	Raspberry Pi 3 Model B+	1	each	RS components	B+	Donated	$0.00	www.raspberrypi.org
1.02	Kuman 7 Inch Capacitive Touch Screen TFT LCD Display	1	each	Kuman	SC7B	$52.99	$52.99	www.kumantech.com/kuman-7inch-tft-lcd-capacitivetouch
1.03	Kuman 7 Inch Touch Screen Case	1	each	Kuman	SC7B-1	$10.99	$10.99	www.kumantech.com/kuman-7-inch-raspberry-pi-touch-scre
1.04	S-Type Load cell	1	each	Dr. Gauss	B077YHLZGQ	Donated	$0.00	www.amazon.com/Portable-High-Precision-Pressure-Tensio
1.05	Pressure Sensor	4	each	ICStation	11690	$16.39	$65.56	http://www.icstation.com/100kg-thin-film-pressure-sensor-f
1.06	ADS1115	3	each	adafruit	1085	$14.95	$44.85	https://www.adafruit.com/product/1085
1.08	Dual Motor Driver Module Board	1	each	CES Deals	L298N	$2.23	$2.23	https://www.ebay.com/p/Dual-Double-h-bridge-L298N-DC-S
1.09	IRM-60-24ST	1	each	OnlineComponents	IRM-60-24ST	$17.16	$17.16	https://www.onlinecomponents.com/en/mean-well/irm-60-24
2.00	**Actuator subassembly**							
2.01	Linear Actuator	1	each	Windynation	LIN-ACHD-18	$185.99	$185.99	https://www.windynation.com/Large-Actuation-Weight
2.03	10 AWG 10 Gauge Silicone Wire	1	each	Amazon	B07567TDXJ9	$15.98	$15.98	www.amazon.com/Electrical-Silicone-Flexible-temperature
2.04	30 Ft Extension Cord Red with 4 Electrical Power Outlets	1	each	Amazon	B07G1D8VV1	$32.99	$32.99	www.amazon.com/Extension-Cord-Electrical-Power-Outlets
4.00	**CenterBench subassembly**							
4.02	2"x4"x96" Lumber	3	24 feet	Home Depot	106147	$3.17	$9.51	www.homedepot.com/p/2-in-x-4-in-x-8-ft-2-Ground-Contact
4.03	4"x4"x10' Lumber	2	20 feet	Home Depot	4220254	$9.88	$19.76	www.homedepot.com/p/4-in-x-4-in-x-10-ft-2-Pressure-Treat
4.04	23/32" x 2' plywood	4	8 feet	Home Depot	1502108	$15.84	$63.36	www.homedepot.com/p/Sanded-Pine-Plywood-Common-23
4.05	#8x2.5"Phillips Bugle Head Screws	2	pack of 86	Home Depot	134228	$3.98	$7.96	https://www.homedepot.com/p/Grip-Rite-8-x-2-1-2-in-Phil
4.06	1/4" Dowel Rod	1	48 in	Home Depot	145825	$0.86	$0.86	https://www.homedepot.com/p/4ft-0-1-4-in-x-1-4-in-x-48
4.07	Wood Epoxy Glue	1	8 oz	Home Depot	638489	$3.97	$3.97	https://www.homedepot.com/p/Gorilla-8-oz-Wood-Glue-62
5.00	**BottomWheels subassembly**							
5.01	POWERTEC T5000 Workbench Caster Kit	1	kit (4 of each)	Fast Tools	B005XST2LO	$53.99	$53.99	www.amazon.com/POWERTEC-T5000-Workbench-Caster-
6.00	**Waste/Plexiglass subassembly**							
6.01	1/8 X 48 X 96 Polycarbonate Sheet-MOTOR FREIGHT ONLY	2	each	FredeFace	PC124896	$116.00	$232.00	https://fredeface.com/shop/site_us/store/html/product/1/ht
6.02	Bracket for Plexiglass	24	each	DrawingInPrint	N/A	Donated	Donated	www.drawinginprint.com
-	-	-	-	-	-	**Total:**	**$820.15**	

Figure I.1 Bill of Materials

J. Acceptance Criteria

Specifications	Parameter	Value	Parameter	Value	Parameter	Value	Reasoning
Table Dimensions	Height	min. 4' max. 4.5'	Width	2'	Length	4'	The height is chosen to have room to fit everything needed. The length was chosen based on the parameters for the bridges and to give enough room for varience. And width was chosen based off mobility, stability, and materials on the inside.
Table Material	Wood	1"	Legs	4x4 inchs			These were chosen due to them being lighter weight than metal but still durrable enoughto support the bridge distructions
Linear Actuator	Max Load	750 lbs	Stroke Length	24"	Power	24v	This was decided based off the max. load bridges held in previous competitions as per Dr. Garcia. The stroke length is chosen to have plenty of room to move based off the type of bridge, ie. supports underneath, and any difflection the bridges have.
Laser/Photobeam	Measurme	2-200 mm					This was chosen because it is precise enough for very little deflection but still allows for extra bendy bridges
Compression Pads	Max Load	250 lbs	1 at each corner				These are being used for the tension test. The max load is lower because the load will be split up between all 4
Plexiglass Sides	Thickness	0.125 inch					This is so the inside can be monitered for issues and gives a cool visual for the contestants
Raspberry pi	model	3b+	Power	5v	RAM	1 gb	We are using this model because it can be used with matlab
Caster Wheels	amount	5					Wheels are being used to increase mobility. They will be locking wheels. 5th wheel in center of table for stability.
Guiding Rails for clear side							will be attached to the legs and used to secure the plexiglass sides.
Rollar Rails for table top	length	2 ft	amount	4			will be used to slide the table halves apart to accomedate for the different bridge sizes

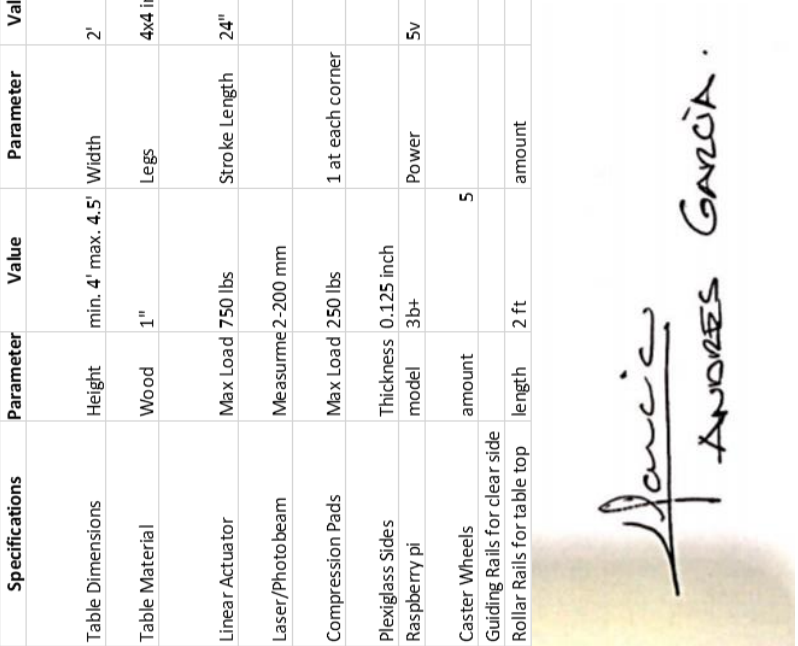


Figure J.1: Table of Requirements and sponsor signature