F31: TransporTable

Project F31: Design Collaboration Space Final Design Report

Sponsor: Peter Schuster

June 3, 2021

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Statement of Disclaimer

Abstract

This document is a Final Design Review (FDR) report for team TransporTable, a quartet of mechanical engineers at California Polytechnic State University, San Luis Obispo (Cal Poly). It chronicles our design and validation process through final design phase. Our project: to design and test concepts for a stackable table that streamlines group work. After conducting user/sponsor interviews and background research, we found that many products already exist, but none meet the specific blend of requirements set out by our sponsor. They include fast deploying/stowing times, durability, stiffness, and manufacturability. We ideated on the table's functions, distilling many ideas into three concept designs. After prototyping each design, we found the best design to be a trapezoidal base, square top table. We tested subsystem prototypes to make detailed design decisions, presented in the final design chapter. Detailed manufacturing of the trapezoidal table verification prototype as well as its associated verification processes has been conducted and documented in the report. Deficiencies and recommendation acknowledged from the verification process are listed to further improve the final design of the table.

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1.0: Introduction

This document outlines the challenge, background, scope of work, design processes, and a final concept design for project F31: Design Collaboration Space. The project was initially proposed by Peter Schuster, a professor at Cal Poly. The core team consists of four Cal Poly mechanical engineering students: Jung Kim, Ellie Kitabjian, Christopher Macias, and David Yang.

Many classes at Cal Poly revolve around group work and would benefit from a collaborative meeting space. However, design teams do not meet often enough to warrant a dedicated meeting facility on campus; an adaptable space provides the best balance of individual and group functionality. Custom tables will be the centerpieces of this space in collaboration mode but need to stow when not needed.

Tables are the centerpiece of any collaborative space; a well-designed table will be the focus of our design efforts. The following is a brief summary of this report's content:

- **Background:** Compilation of background research from all members.
- **Objectives:** Establishes goals, deliverables, and judgement criteria for project.
- **Concept Design:** Chronicles the ideation process into our final design recommendation.
- **Final Design:** Justifies the final design recommendations.
- **Manufacturing:** Lays out steps of procurement, fabrication, and assembly.
- **Design Verification:** Defines tests and resources to quantify design and provides verification results with associated recommendations.
- **Project Management:** Introduces key management skills used in the project.
- **Conclusion / Recommendation:** Key points to wrap up the report.

2.0: Background

Our background research provided us a foundation of knowledge preceding preliminary design process. We conducted user/customer surveys to develop overall goals, researched and listed previous products/patents to be inspired by existing solutions, conducted case studies, and researched regulations to understand how industry quantifies a "well-designed" table.

2.1: User/Customer Research

The student group project-targeted nature of this project means that our design team of mechanical engineers happens to fit the user description perfectly (save the unfortunate irony of the pandemic that we currently live in)! Human-centered design is important to this team and the success of this project; our personal experiences with the problems we hope to solve and our visions for the perfect solution have given us a great starting point, but we looked to user/customer research to broaden our scope.

2.1.1 User Surveys

We wanted to figure out which existing problems are the most significant to the users and what components are the most important to them in design spaces like the one we are going to build. We released a survey to other senior project students.

The results yielded key takeaways that will help us with our decision making. 45% of respondents noted shape and size as the most important characteristic of table design. Surprisingly, height was the less important consideration, as only 18% of respondents marked it as "very important". As for shape, many students indicated they preferred straight edged tables to circular ones. Many also said they would like to have a table where all the members of the team can face each other, and hexagonal tables were suggested as an option to satisfy this want. In an open response, question, 50% of respondents noted a cramped workspace as a common issue. In addition, most users desire a smooth or wooden table to work on. This will be a promising surface type going forward.

2.1.2 Sponsor Meetings

We also conducted recurring meetings with our sponsor, Professor Peter Schuster, and received a better understanding of the customer needs and wants. The customer in this case is Cal Poly and Professor Schuster gave us a unit cost estimate, listed later in the report. Manufacturability and assembly from off-the-shelf parts is paramount, but easy storage and durability are the university's benchmarks for success that will ensure the tables' utilization for years to come.

2.1.3 Use Cases

Our team happens to be the ideal target audience for this product, college M.E. students, so we took some inspiration from our own setups (as shown in Figure 1). We brainstormed several use cases to help define our functional requirements, eventually realizing that table usage typically involves:

- A laptop.
- Engineering pad.
- A notebook, textbook, or some other reference material.
- Calculator/writing utensils.
- Miscellaneous accessories (water bottle, snacks, etc.)

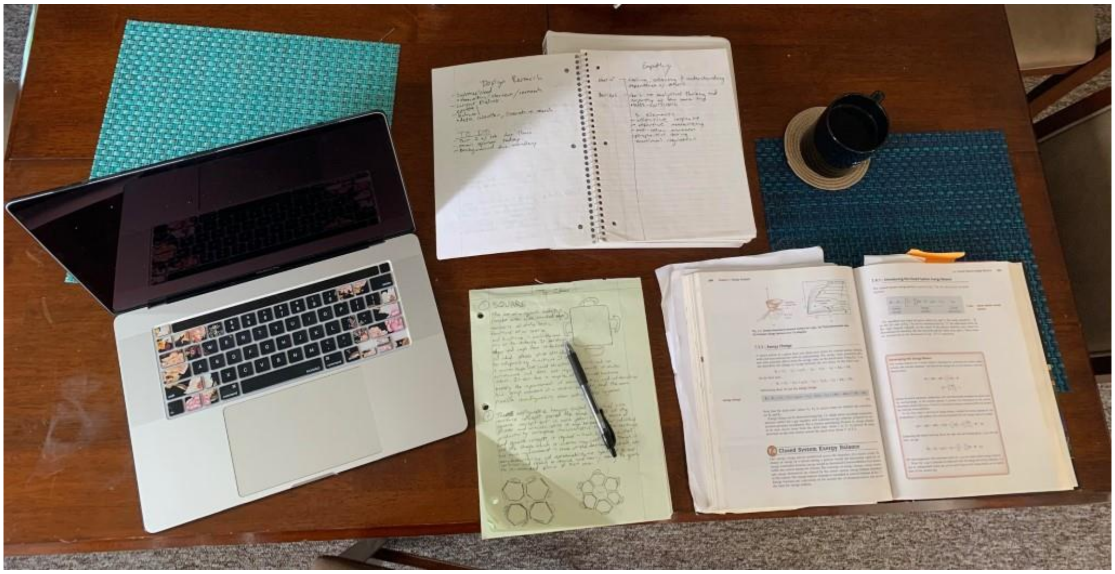


Figure 1: A typical studying spread, which occupies a 36”x24” footprint.

2.2: Previous Products

The search for existing products went beyond the basic table design into those that were compact or had collaboration as a central feature. Below, we have listed the existing table design (Figure 2) used in Bonderson project rooms and some of its specifications in Table 1 and Table 2.

Figure 2 below portrays the design of the existing tables in Bonderson’s project rooms, which has a single axis folding tabletop for a quick deployment/folding and with attached caster wheels on the bottom of the legs for mobility.

Figure 2: Existing Table design in Bonderson project room

The major dimensions and materials are recorded in Table 1 below.

Table 1: Existing table design parameters

Tabletop Dimensions	66 x 30 inches
Tabletop Thickness	1.25in.
Total Height	28 in.
Base Footprint	48 x 24 inches
Tabletop Material	Laminated MDF
Leg Tube Size	1in. ID
Casters	4, locking
Wobble	1.3±0.2°

The table has shakiness consistent with its single-axle design, reflected in the "wobble" parameter. Appendix A contains the detailed calculation and measurement method.

The existing tables are also very efficient in terms of stacking. Figure 3 below shows two stacked tables.

Figure 3: Two tables in their stacked configuration.

The stacking appears very compact – the quantification is described in Table 2 below.

Table 2: Stacking efficiency of the Bonderson tables.

Footprint of single table	13.75ft.^{2}
Footprint of two stacked tables	17ft.^{2}
Area Increase	24%
Area Stacking Efficiency	76%

Appendix A details the stacking efficiency calculations.

Table 3 and Table 4 below detail several products representative of existing categories. They are split into tables meant to be used alone or grouped with others.

Table 3: Existing Single Tables

The "Handy Foldup Utility Table" attempts to solve the problem of not having enough space to store a table. It compacts into the configuration show by first folding in the legs and then folding down the top surface. It meets the need of compact storage but is not designed for durability or multi-functional use.	
The "Catskill Craftsmen" table is also designed to fold compactly for easy storage. The top surface is divided into two flaps that can be folded down (shown here with one down and one up). In addition, two of the table's legs fold inward when not in use. This table is too small to fit our needs.	
The "Bora Centipede Workbench Tabletop" is designed to be used with the collapsible leg system shown. The tabletop can be folded in half and has a built-in carrying handle. This product is both durable and easy to store but, it is not suitable for other uses such as writing and is visually unappealing.	

Table 4: Existing Grouped Tables

The "Herman Miller: Everywhere" tables are another design based around individual tabled combining into a larger table. The tables used are of two different shapes so they can be used to create multiple configurations to suit the needs of the room. The casters allow for easier transport. The tables are not designed for compact storage.	
The "Global Zook" collaborative tables are a set of six individual tables that can be joined into a larger configuration. This helps facilitate collaboration since groups can combine tables more easily. Standard tables require more time and coordination to reconfigure. The main disadvantage is the fact that the tables cannot be made more compact. Storing the tables would require taking up the same amount of room.	
SMARTDesks is a collection of furniture designed with collaboration as a central feature. The product shown is a desk that can be combined with other desks using a central docking station. The individual desks are easily transported using casters and are adjustable in height. Other versions of this product have built-in laptop support. Like other tables, it is not designed for compact storage.	

Other existing products have similar features and designs. The tables with the most features (e.g., transportability, re-configurability, adjustable height) lack any compact storage function. From the examination of available solutions, it is clear there is still a need for table that can meet all the needs of the problem.

2.3: Case Studies and Technical Research

While few case studies cover furniture design in detail, numerous case studies covering holistic workspace design exist. Steelcase's TELUS redesign study records the process of a considerate redesign, from appropriate stakeholder involvement to effective implementation strategies, including time for product dealers to show "employees how to adjust their new chair[s]", as well as ergonomics posters "posted throughout the space" (Steelcase). This extra time allowance for ergonomics training can be extremely effective – a paper finds that ergonomics training can “almost double the reduction” in process cycle times compared with untrained users of ergonomic equipment (Robertson).

Christine Congdon writes on the functional diversity of a collaborative workspace in “Balancing “We” and “Me”: The Best Collaborative Spaces Also Support Solitude”. She notes that “the number of those who don’t have access to places to do quiet, focused work is up 13%” (Congdon). To this end, she posits that private spaces can be assessed in terms of their acoustical, visual, and territorial insulation. Though our project scope is to develop a *collaborative* workspace, our designs should not impede privacy if the need arises.

In the January 2013 edition of *Learning Environments*, Peter Lippman addresses a common thread in collaborative spaces: the need to “include a variety of defined areas to support individual, 1-to-1, small group, and large social groupings” (Lippman 2). While flexibility is a typical requirement, Lippman provides a useful framework for evaluating flexibility via the four categories. In the study, he notes the space “must be both differentiated and integrated”, emphasizing the importance of furniture reconfigurability (2).

Jarmo Sillanpää provides a useful method for quantifying ergonomic design in “A New Table for Work with a Microscope”. His team describes a common set of tasks associated with microscope work, measuring electromyographic activity in the tester’s neck muscles. The results showed “statistically significantly lower muscle activity on both sides of the neck,” proving the benefit of ergonomic design.

No matter the method or technology, good workplace culture is the most effective way to promote ergonomics and reduce discomfort. According to the article “Stand Up and Move; Your Musculoskeletal Health Depends on It” by Kermit Davis et. al., “The key to better worker health and well-being is encouraging routine movement around the office” (Davis et. al). Our development of a reconfigurable table invites consistent movement, and therefore provides a good ergonomic foundation going forward.

Technical research yielded an interesting design technique: “Kansei Engineering”. In the *International Journal of Industrial Ergonomics*, researcher Mitsuo Nagamachi simply describes it as “translating technology of a consumer's feeling and image for a product into design elements” (Nagamachi 1). Figure 4 below depicts this process. In its simplest form, a tree diagram is drawn. At the top sits a word used to describe the product; the proceeding branches contain increasingly specific details that terminate in detailed design criteria.

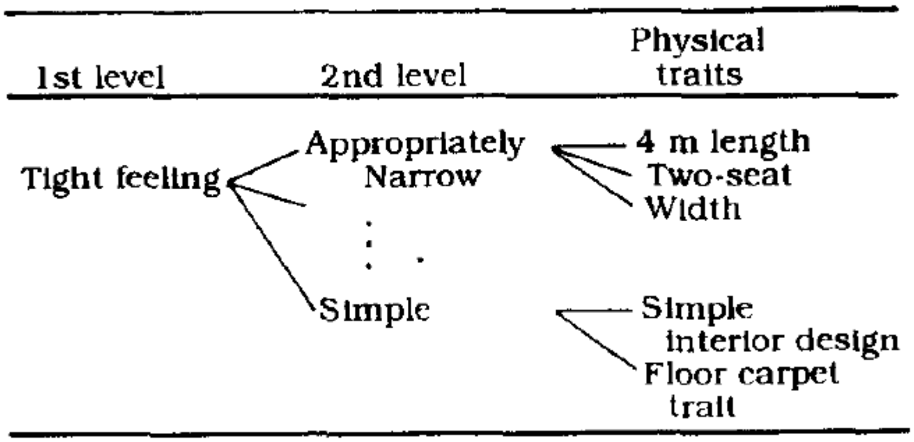


Figure 4: An example of simple (Type I) Kansei engineering.

This technique will pair well with user surveys and focus group interviews: as we develop more detailed consumer profiles, we can create trees with greater specificity.

In conclusion, technical research helped us learn about the subtle effects that furniture design and layout have on a student's collaboration. Regular movement and ergonomic training are two factors critical to increasing productivity: we will provide approachable user guides along with our final prototype to encourage movement and ensure users know the full functionality of the table. Our research into Kansei engineering provided us a method for selecting materials and geometry going forward, and Sillanpää's work in quantifying ergonomic improvement will be a helpful resource for anyone looking to extend our work into an individual ergonomic domain.

2.4: Patents

The patent research mostly focused on finding existing patents that can aid us in meeting our customer needs (outlined in Section 3.3). Out of nine relevant patents, listed below are the five existing patents that are most applicable. This section introduces the key design ideas incorporated in the listed patents and how these ideas may enhance our project as well as insights for adaptation into our designs.

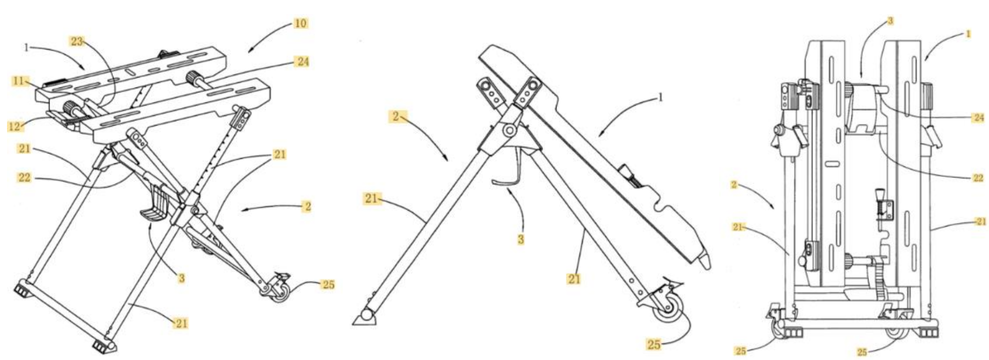


Figure 5: Foldable worktable US7757999B2 (2006)

Table 5: Selected specifications for US7757999B2 (2006)

Specification	Description
Quick Deployment and Breakdown	Two-step deployment, folding leg, and unlatching tabletop
Compact storage	One plane foldability with a folded height of the leg support only
Simple Structure	Two piece crossed leg supporting the top portion
Moderate durability	Expected wobble from lack of support

Takeaway from the patent in Figure 5: quick deployment breakdown and compact storage function. Table 5 lists other points of interest with this patent.

Our team's insight - Height might be adjustable by adding multiple latching point from the tabletop to the support connection, adjusting the angle of the crossed leg supports. That current design is a worktable; if the design is scaled to be a table to seat four people, current functional advantage might not apply and not as appealing as it is now. Deployment and breakdown procedure might be complicated due to the bigger size of the tabletop accommodating four people but might adopt the idea of a folded tabletop from the patent in Figure 5. To improve durability, light material shall be used for tabletop manufacturing in complement of lacking leg support. Also, supporting table legs might interfere with students' legs when sitting down.

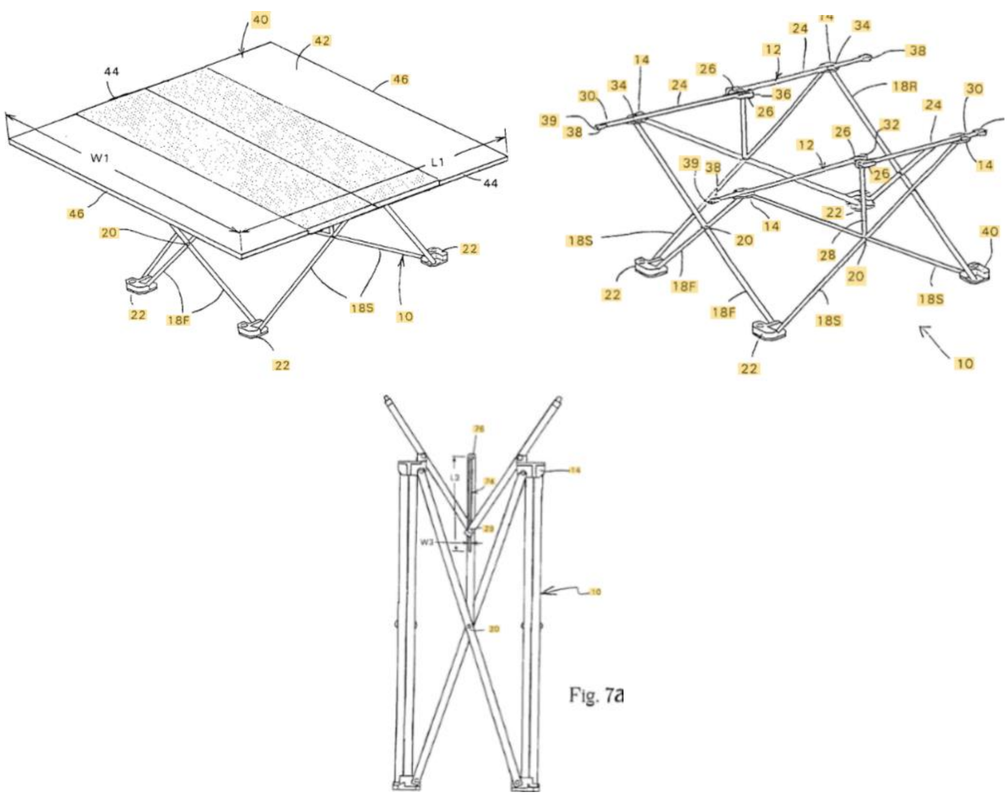


Figure 6: Portable table US20050199162A1 (2004), joint link legs with folding top.

Table 6: Selected specifications for US20050199162A1 (2004).

Specification	Description
Very quick Deployment and Breakdown	Joint-link-mechanism allows one-motion deployment and breakdown
Moderate compact storage	One plane foldability with a folded height taller than figure 2 design
Complicated Structure	Numerous linkages used for the support
Moderate durability	Leg bases are placed under the boundaries of the tabletop which makes the table to easily tip over, Multiple potential failure points at the linkage joints

Takeaway from the patent in Figure 6Figure 6: quickest deployment – joint mechanism that folds tabletop and the supports simultaneously. Table 6 lists other points of interest with this patent.

Our team's insight – if a single joint is found at fault, the whole mechanism may not function properly. Multi-link design creates non-durable and non-simple structure compared to the design which uses a fewer number of links.

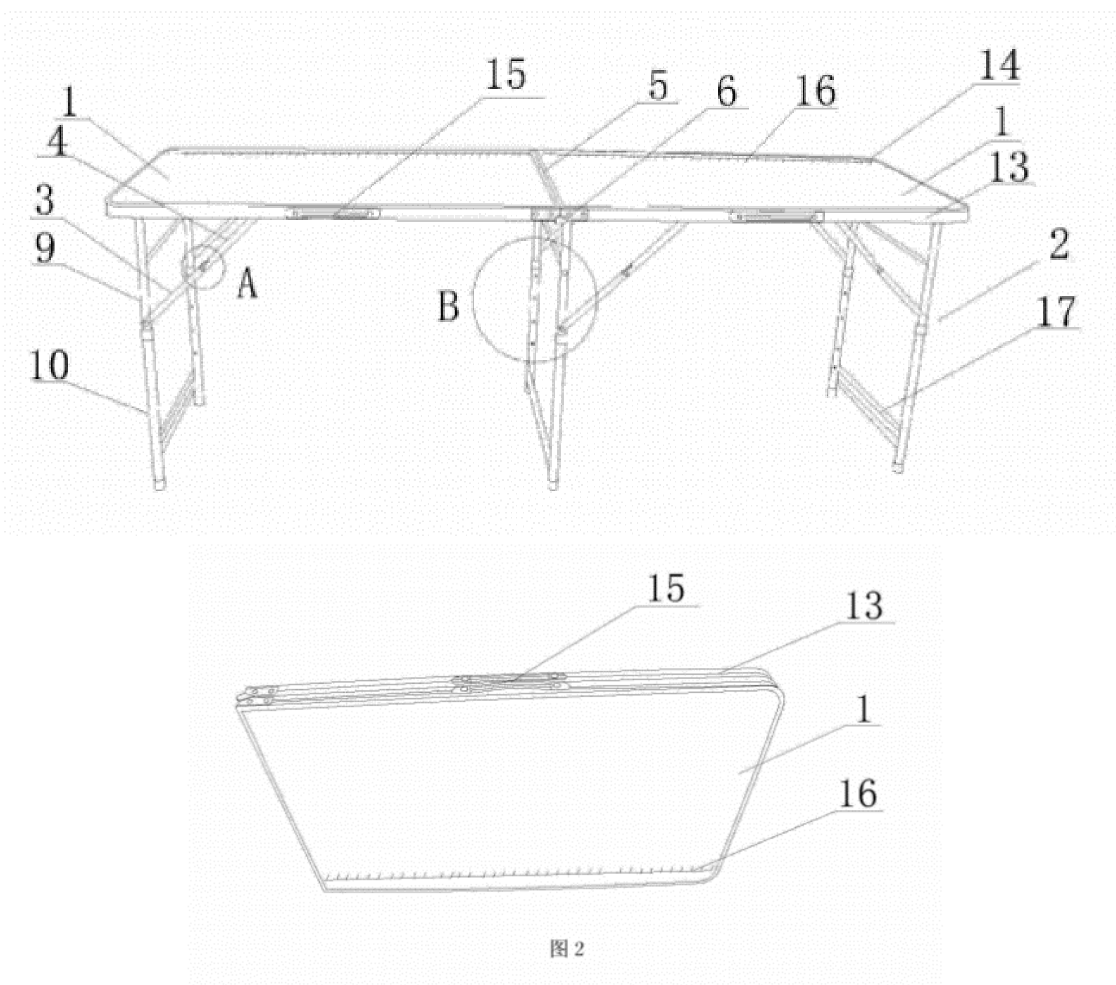


Figure 7: Folding table CN203709519U (2014).

Table 7: Selected specifications for CN203709519U (2014).

Specification	**Description**
Moderate Deployment and Breakdown	lift and turn the table sideways, fold in the supporting legs on each side, and fold the table in half. Two people might be recommended
Very compact storage	Table assembly folds in half size of the table top in one plane, exterior side of the folded tabletops encloses the leg assembly
Simple Structure	Three piece supporting legs and one folding tabletop
Good durability	Vertical leg supports which are relatively sturdy compared to the above patents' angled leg supports

Takeaway from the patent in Figure 7: Best for compact storage and even nesting using the smooth surface of the tabletop, supporting legs are not exposed. Three vertical leg support which enhances durability. Table 7 shows other features to consider with this patent.

Our team's insight – horizontal bar supports connecting the individual vertical leg supports eliminate possible wobble of the table. Vertical legs withstand vertical loads better but might be vulnerable to the horizontal loads.

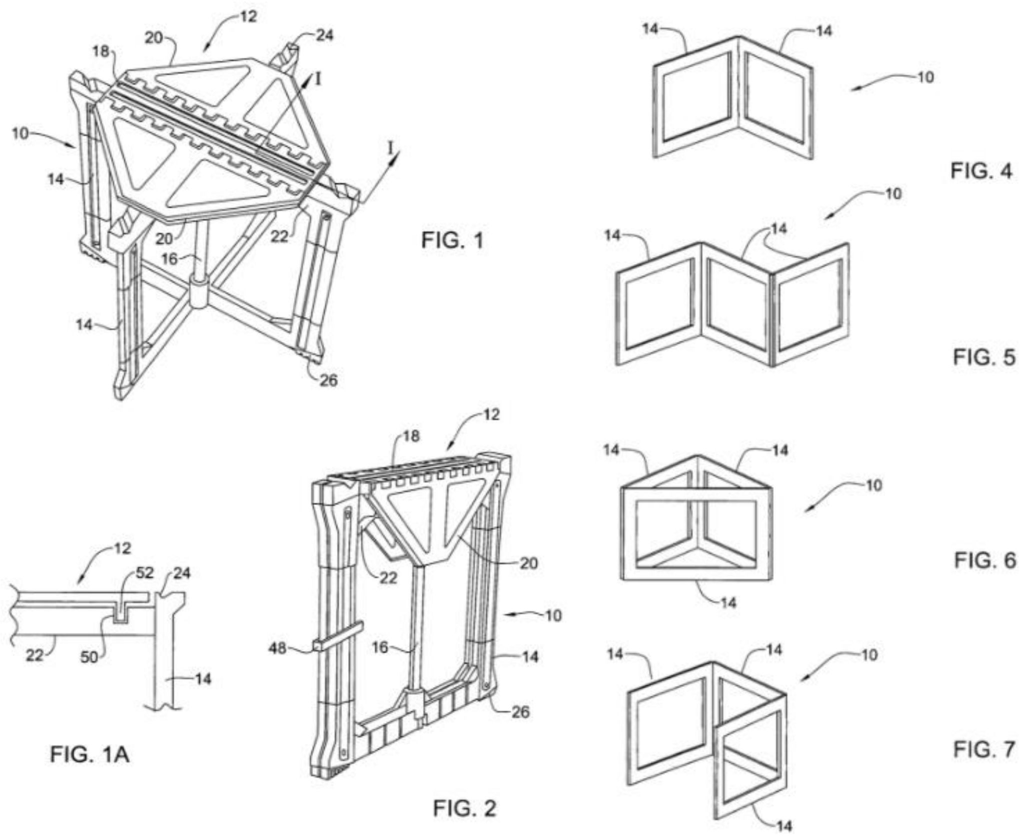


Figure 8: Collapsible worktable US7415933B2 (2004**),** Y-axis cross folding legs**.**

Table 8: Selected specifications for US7415933B2 (2004).

Specification	Description
Quick Deployment and Breakdown	2-step; fold the two support legs sideways and fold down the top
Good compact storage	one-plane foldability. Storage height of the support legs only
Simple Structure	Two-piece leg assemblies and a folding top
Good durability	Vertical legs with horizontal connections in between

Takeaway from the patent in Figure 8: Y-axis folding support legs, and horizontal support between the vertical legs at the floor level. Table 8 shows other features to consider with this patent.

Our team's insight: top must be a square shape; if rectangular, top won't be able to fold diagonally being symmetrical. Since every edge must be at the same length, dead space exists in the middle of the table where no one may reach and be used (similar to circular shape tables).

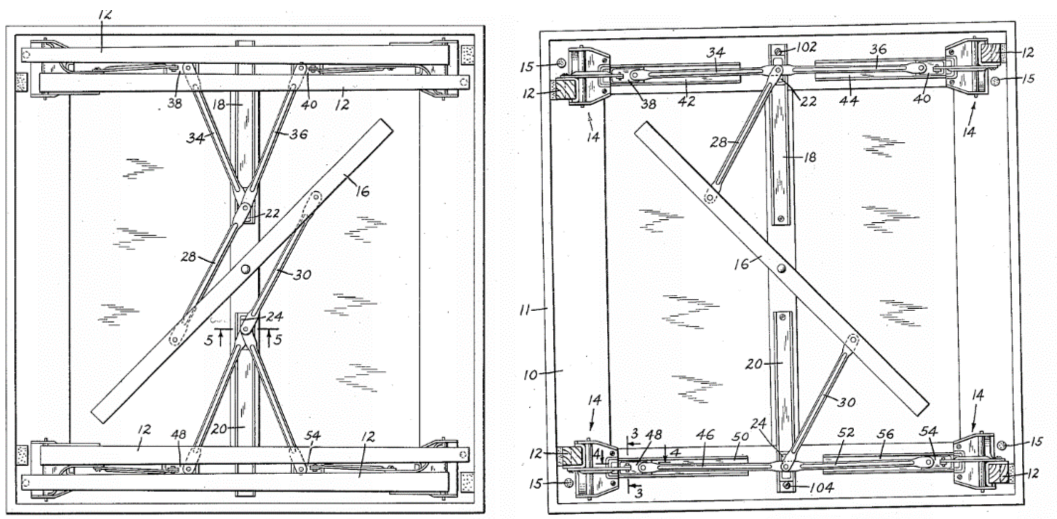


Figure 9: Leg Positioning mechanism for folding tables US2527045A (1947).

Table 9: Selected specifications for US2527045A (1947).

Specification	Description
Quick Deployment and Breakdown	2-step; Enhancement from Figure 7 Folding table where legs are not folding individually but fold and unfold in unison
Good compact storage	one-plane foldability. Storage height of the tabletop width
Complicated structure	Additional 15 linkage from a conventional fold-leg table.
Moderate durability	Wobble resistance as all legs are connected to each other. However, multiple use of linkage creates multiple potential failure points.

Takeaway from the patent in Figure 9Figure 9: Quick deployment and breakdown. Resistance to wobble enhanced from the positioning mechanism. Table 9 shows other features to consider with this patent.

Our team's insight: Linkage and joint shall be designed with materials that withstand the expected load of the table. Manufacturability decreases from the conventional folding tables as this design demands 15+ more parts added to the assembly. Maintainability and diagnostics of failure shall require a person with certain measure of the expertise of the design.

2.5: Regulations

The Business + Institutional Furniture Manufacturers Association (BIFMA) sets standards for furniture used in commercial, educational, and other institutional use. The BIFMA classifies tables into three categories. Ours will be a category three: a height of more than 24 inches and a surface area larger than five square feet. The following are some test standards for table products that are applicable.

Table 10: Relevant BIFMA standards.

Test	Description	Parameter
4.3	Stability Under Vertical Load Test	125 lb. load applied at edge
4.4	Horizontal Stability Test for Desk/Tables with Casters	10 lb. tip force applied perpendicular to casters
5.2	Concentrated Functional Load Test	200 lb. load at weakest point
5.3	Distributed Functional Load Test	1.5lb/in load distributed
5.6	Transaction Surface Torsion Load Test	75 lb. load attached with cable and hanging off edge
6	Top Load Ease Cycle Test	200 lb. cyclic load
7	Desk/Table Unit Drop Test	Drop height 2.4-4.7 in.
8	Leg Strength Test	Force up to 100lb, applied perpendicular to leg
15	Work Surface Vertical Adjustment Test	100 lb. load raised using adjustable height mechanism

The tests in Table 10 are designed to ensure the furniture will not fail due to daily use and other load cases such as a person sitting on the table. Any table design we create should be compliant with the tests to ensure both user safety and product durability.

3.0: Objectives

This section compiles the goals, evaluation criteria, and product deliverables for the project to ensure synchronicity between the sponsor and our design team. We establish a problem statement based on our user and sponsor interviews – this informs our list of customer needs, which are then quantified in the Quality Function Deployment (QFD) and engineering specification table.

3.1: Problem Statement

Appendix B:Consumer Profiles, contains the full list of problem statements that we developed. Each of them helps us to consider a slightly different audience with different needs, but our main problem statement is as follows:

Existing collaborative tables lack the key combination of transportability, compact storage, surface quality, and durability for group projects. College students need an ergonomic, multifunctional table unit capable of supporting all levels of interactive work, from one-on-one tutoring to large group prototyping sessions to maximize productive time in a busy day.

3.2: Boundary Diagram

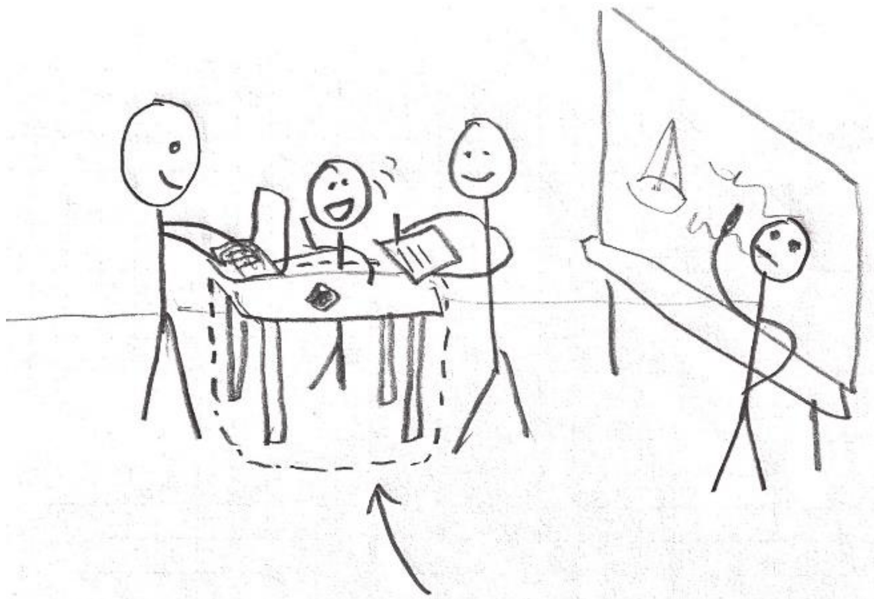


Figure 10: The boundary diagram indicates the scope of our project: developing a table to encourage group work.

The boundary diagram (Figure 10 above) shows four people working together within the design space. Also included in the boundary diagram are some of the materials that would go on top of the table and the figures shown are congregating around a table. The table is outlined with a dotted line as all components that occupy that space and perform those functions are going to be designed by the team.

3.3: Customer Wants/Needs

The needs and wants of our customer were determined through discussion with our sponsors about the most important characteristics to design for. The sponsor in our case represents both the wants and needs of future students who would put our product to use, and Cal Poly who would be responsible for the purchase and future production of our product. Many of these wants and needs were formed as a response to the lack of key elements in the current tables in Bonderson. A series of short surveys of engineering students were conducted to better understand the wants and needs of the user in this case.

- Compact Storage: Many of these products should be stored in a footprint about the size of a single product.
- Durability: The product should stand up to years of negligent student abuse.
- Economical: The cost of parts should not exceed the proposed value.
- Quickly deployable (from storage): The product should deploy from a stored state in a matter of seconds.
- Quickly re-configurable: Users should be able to reconfigure the products to support their work stage in a matter of seconds.
- Manufacturable in-house: Junior shop techs should be able to build and maintain the tables at little cost to the university. These techs should be able to do machining, welding, and other simple methods of assembly in the shop setting.
- Multifunctional surface(s): Since a wide range of activities occur in the M.E. program (prototyping, studying, computer work, drafting, etc.) the product's surface should be conducive to a range of activities.

3.4: Quality Function Deployment (QFD) Overview

The Quality Function Deployment (QFD) or House of Quality chart, is a matrix (Appendix C:QFD (House of Quality)) that helps to correlate engineering tests with customer requirements. Our QFD begins by defining the various customer groups: to this end, we developed a collection of customer profiles (Appendix B:Consumer Profiles). From there, four main customer groups were chosen. The sponsor requirements were derived from two meetings with the sponsor, and we rated each requirement by customer group to understand the overall importance of each requirement. Next, we cross-referenced our list of engineering specifications (tests) to ensure every requirement could be tested or evaluated.

Stability, reconfigurability, and the ease of cleaning are frequently tested befitting their importance. One particularly striking characteristic of our QFD is the high number (seven) of tests that evaluate safety; this highlights the importance of designing a safe product. Notably, pinch points are not explicitly mentioned in the QFD but will be evaluated during deployment and usage testing. A specific weight target is also absent from the QFD – this spec requires more work, as increasing weight improves stability, but a heavier table may be harder to use. Section 4.6 offers a more complete explanation.

Engineering Specification Table

Table 11 lists criteria which will be used to constrain the final design of the table. The risk of failing to conform to each criterion is noted as low, medium, or high (L, M, H respectively). Below the table are descriptions of each specification.

Table 11: Engineering specification table derived from QFD.

Spec. #	Spec. Desc.	Requirement or Target (units)	Tolerance	Risk	Compliance
1	Compact Storage	3 units/1.5x stack dimension	Min	M	T, I
2	Table Height	30 in.	±2 in.	L	I
3	Deployment Time	30 sec.	Max	H	T
4	Breakdown Time	45 sec.	Max	H	T
5	Cost	$350	Max	M	I
6	Load Tipping Test	125 lb. load at edge	Min	H	T
7	Concentrated Load	200 lb.	Min	H	T
8	Drop Test	2.4 in.	Min	M	T
9	Leg Strength	100 lb.	Max	H	T

Specific tests will be conducted for each criterion:

1. **Compact Storage:** Four tables shall fit in a footprint no larger than 1.5x its stacking direction, visualized in Figure 11 below.
2.

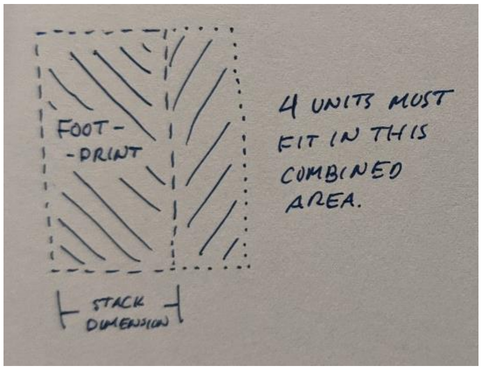


Figure 11: Measurement criteria for Spec 1: Compact Storage.

3. **Table Height:** This will simply be a measured dimension. Derived from BIFMA G1-2013 Ergonomics Guidelines.
4. **Deployment Time:** The highest-risk objective is deployment time. The storage/usage configurations will be critical in producing a product that differentiates itself from the competition. To this end, there are existing quick-deploy table solutions, but these are primarily for woodworking tool benches. A similar design could be adapted.

5. **Breakdown Time:** This will be tested in similar fashion to deployment time. Locking mechanism design will be crucial in developing a fast-breakdown table.
6. **Cost:** Per conversation with the sponsor, the *production unit cost* shall not exceed the listed cost.
7. **Load Tipping Test:** Test 4.3 in BIFMA standards. A 125lb. load is applied at the most unstable point (determined by analysis); The test fails if the table tips.
8. **Concentrated Load:** Test 4.4 in BIFMA standards. A 200lb. load is applied at the weakest point (determined by analysis) on the tabletop; The test fails if significant deformation occurs.
9. **Drop Test:** Test 7 in BIFMA standards. One side of the table is raised to height depending on the table's weight and released; The test fails if the legs deform significantly.
10. **Leg Strength:** Test 8 in BIFMA standards. A horizontal force up to 100 lbs. (depending on the table's weight) is applied to the legs; The test fails if the legs deform significantly.

4.0: Concept Designs

The creation of our concept designs began with a functional decomposition to better understand the basic needs of the problem. Five subfunctions were identified and further split into more basic functions; ideation sessions were run for each subfunction. Multiple techniques such as brain-dumping and brainstorming were used. On the functional decomposition diagram, numbers on each function distinguish which method of ideation was used: (1) Draw/Image method, (2) Brainstorming method, and (3) Brain dumping method.

Based on the results of the ideation sessions, concept models (such as in Figure 12) were constructed to demonstrate the specific ideas proposed during the sessions. The concept models were added to Pugh matrices**,** which is a tool to relatively rank the features highlighted in different concept models, to determine each model's relative effectiveness in meeting the demands of multiple subfunction criteria.

Figure 12: A small-scale concept model.

Next, a morphological matrix was created to collect the concept model designs for combination into overall designs. These overall designs combined designs from each subfunction to address the problem holistically and were inserted into a weighted decision matrix to select the final designs. All ideation processes are shown in detail in Appendix D:Ideation Results.

4.1: Functional Decomposition

Our ideation process started with developing a functional decomposition (Figure 13 below). It includes the main functions from our customer needs list, along with the sub-functions required to accomplish the main functions.

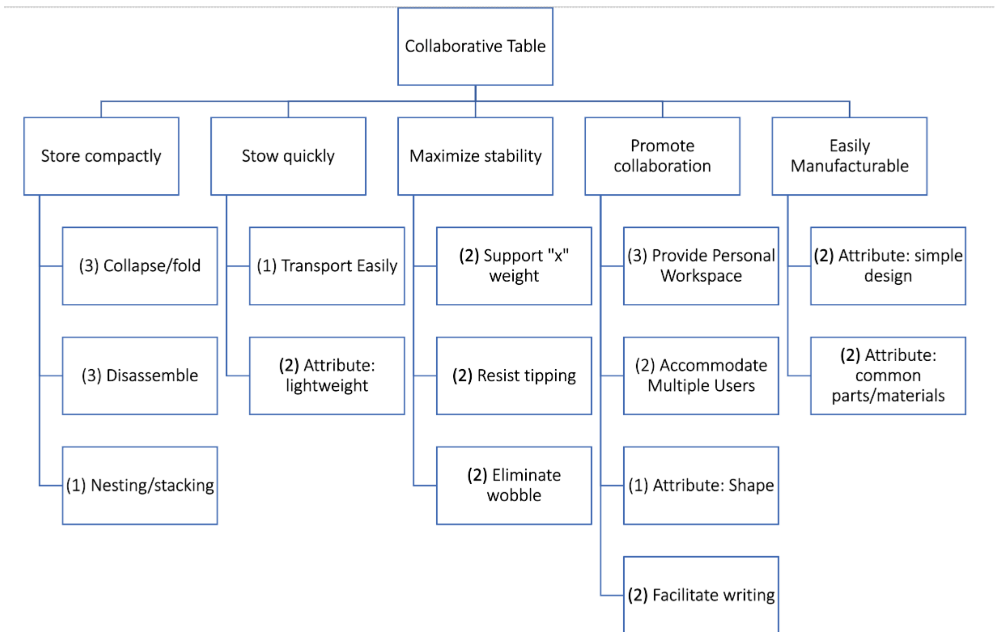


Figure 13: Functional Decomposition Function Tree.

We developed and analyzed individual sub-functions using multiple methods of ideation, including drawing, brainstorming, brainwriting, and brain dumping. We numbered the sub-functions according to a relevant ideation method; each number corresponds to a strategy, conducted in 10-minute sessions:

(1) Draw/Image method: independently make sketches/find images of sub-function solutions, then share amongst team members.

(2) Brainstorming method: collectively talk through sub-function solutions that came to each member's mind. No ideas were excluded during the process.

(3) Brain dumping method: individually come up with sub-function solutions. Afterwards, discuss ways each member's ideas could be used or expanded, frequently via the SCAMPER framework, where elements of an idea are Substituted, Combined, Adapted, Modified, Put to another use, Eliminated, or Reversed.

The results are contained in Appendix D:Ideation Results. We then built 18 functional prototypes, representing the best results of ideation. These functional prototypes were built out of foamboard, cardboard, hot glue, tape, and toothpicks.

4.2: Pugh Matrices

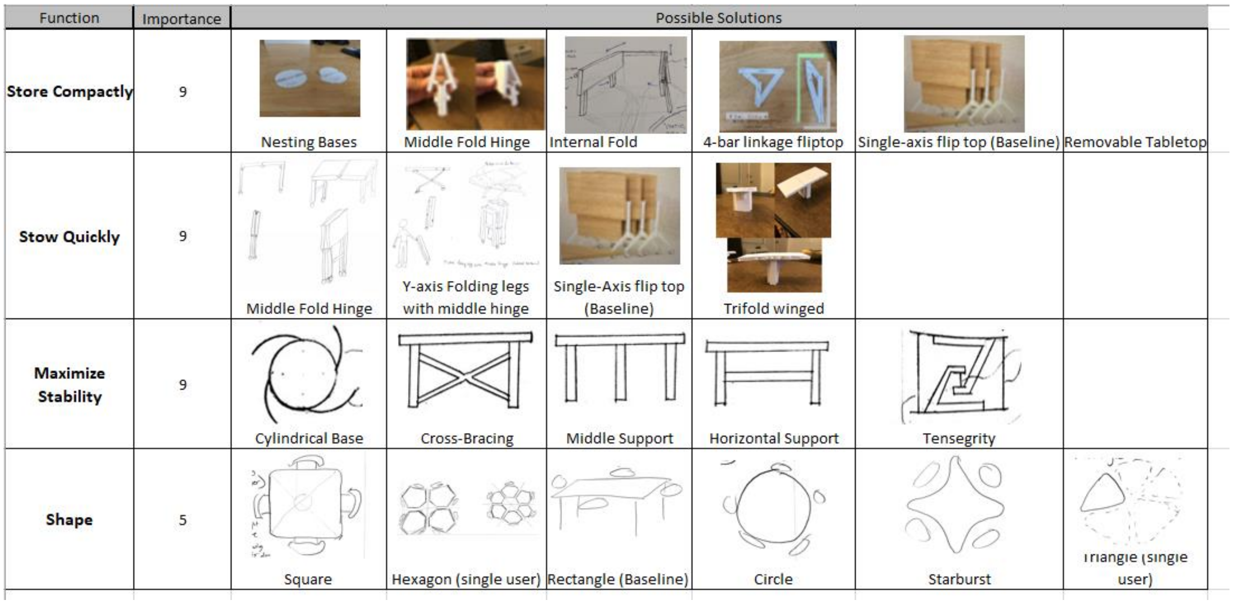
To compare the 18 functional prototypes built upon the previous ideation processes, we created four Pugh matrices to determine each prototype's relative effectiveness in meeting the demands of the multiple subfunction criteria. Functional prototypes, created to demonstrate one of the four major functions from the Functional Decomposition (Figure 13, above), were categorized into their corresponding Pugh matrices shown in Appendix E:Pugh Matrices.

The current table design was used as the datum to compare the functions demonstrated in each of the functional prototypes. Every functional prototype received a +, -, or 0 score to indicate its performance relative to the datum. At the bottom of each Pugh matrix, the total score of the functional prototypes identified whether it was performing better than or worse than the current tables design and the other functional prototypes. Typically, mechanically simple designs edged out more complex ones because of our focus on durability and stability. The best features were carried over to create a Morphological matrix.

4.3: Morphological Matrix

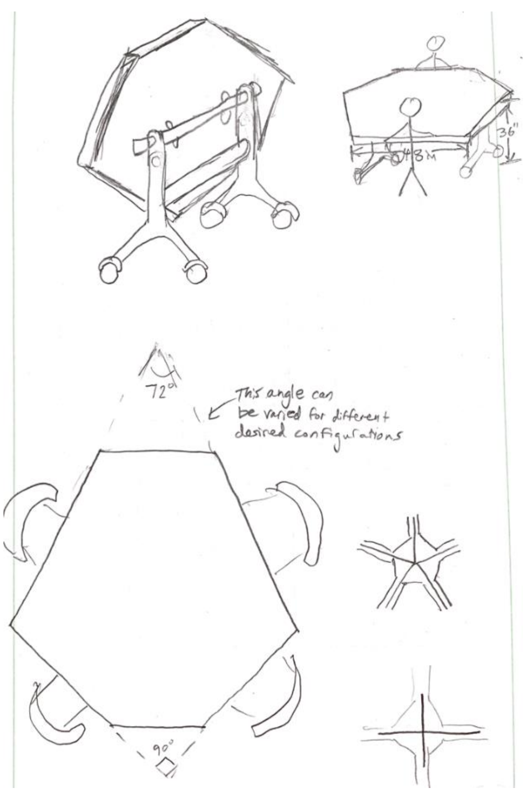
The Morphological matrix in Figure 14 is a collection of the superior functional prototypes chosen from the Pugh matrices (see Appendix E:Pugh Matrices, Appendix F:Morphological Matrix for a larger reproduction). Possible concept prototype designs were created by combining functional prototypes for each function.

In total, five concept designs were created (Figure 15 through Figure 19 below). Each concept prototype chose different possible functional combination from the Morphological matrix to create a wide variety of possibilities and avoid redundancy. Below are the five detailed sketches of the most promising combinations with introductions of their strengths and weaknesses. Brief overviews of each concept prototypes follow the figure captions.



Function	Importance	Possible Solutions					
Store Compactly	9	Nesting Bases	Middle Fold Hinge	Internal Fold	4-bar linkage fliptop	Single-axis flip top (Baseline)	Removable Tabletop
Stow Quickly	9	Middle Fold Hinge	Y-axis Folding legs with middle hinge	Single-Axis flip top (Baseline)	Trifold winged		
Maximize Stability	9	Cylindrical Base	Cross-Bracing	Middle Support	Horizontal Support	Tensegrity	
Shape	5	Square	Hexagon (single user)	Rectangle (Baseline)	Circle	Starburst	Triangle (single user)

Figure 14: Morphological Matrix.



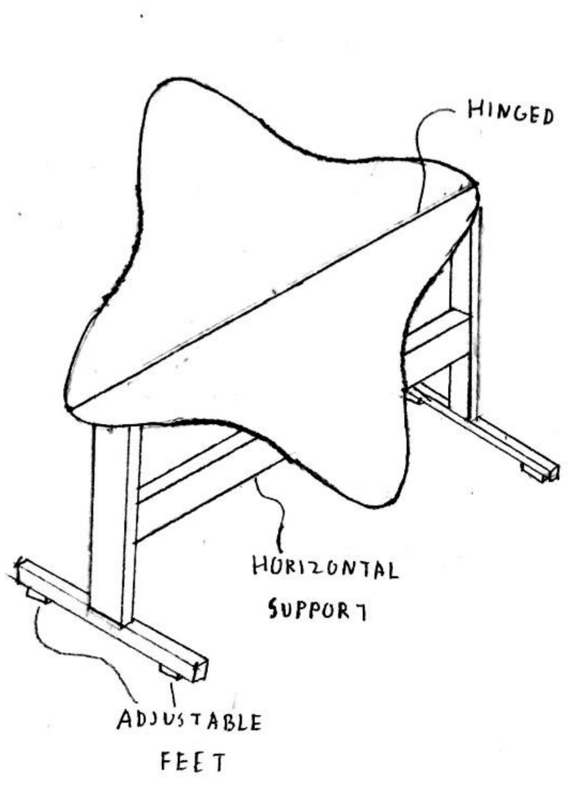


Figure 15 (Left): The first design, a folding hexagon-shaped table.

Figure 16 (Right): The second design, a folding starburst table.

Figure 15 above takes the fast setup and breakdown times of the current tables and modifies the tabletop to promote collaboration. This concept prototype uses functional solutions listed in the Morphological matrix, which are a single-axis flip top to store compactly and stow quickly, horizontal support to maximize stability and a hexagonal shape tabletop to promote collaboration. Notably, the tables can be configured in a four or five table ring for extended group collaboration work.

Figure 16, the starburst tabletop, offers a unique design that places more of the table's area in easy reach of the users. This concept prototype uses functional solutions listed in the Morphological matrix, which are a single-axis flip top to store compactly and stow quickly, horizontal support to maximize stability and a starburst shape tabletop to promote collaboration. Additional features are the adjustable feet which eliminate base wobble, and a robust hinge/lock system minimize wobble at the tabletop.

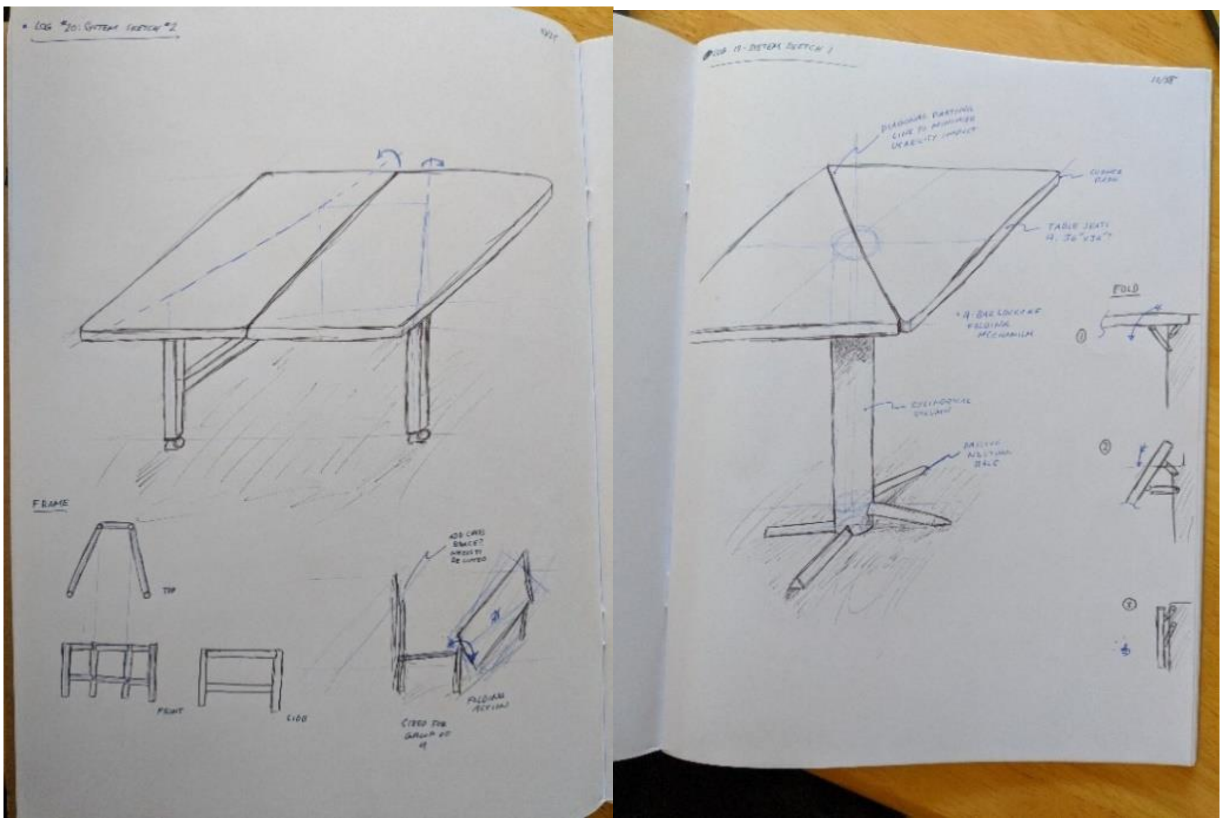


Figure 17 (Left): A fixed, nesting base with a folding tabletop.

Figure 18 (Right): A center column-based design with a nesting base and diagonally split table.

Figure 17 represents a tradeoff between deployment speed, stability, and nesting size. This concept prototype uses functional solutions listed in the Morphological matrix, which are an internal folding tabletop to store compactly, horizontal supports to maximize stability and a rectangular shape tabletop to promote collaboration. The trapezoidal base promotes compact nesting, and the center-split table allows for fast deployment and folding. However, the wider base may limit nesting efficiency. Figure 18 is a center column style table, which utilizes a four-bar linkage to control the folding kinematics. This concept prototype uses functional solutions listed in the Morphological matrix, which are a middle fold hinge tabletop to store compactly, cylindrical base to maximize stability and a square shape tabletop to promote collaboration. center column style table is a useful design for a compact storage without adding too much mechanical complexity.

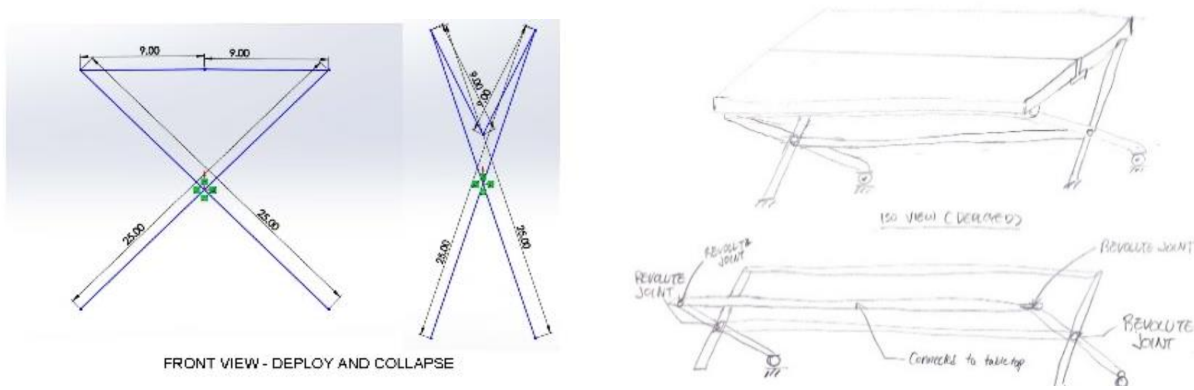


Figure 19: A downward-folding table.

Lastly, Figure 19 is a downward-folding table that has a lightweight frame with a quick folding feature from the middle of the tabletop. This concept prototype uses functional solutions listed in the Morphological matrix, which are a middle fold hinge tabletop to store compactly, y-axis folding legs with a middle hinge to stow quickly, horizontal support to maximize stability and a rectangular shape tabletop to promote collaboration.

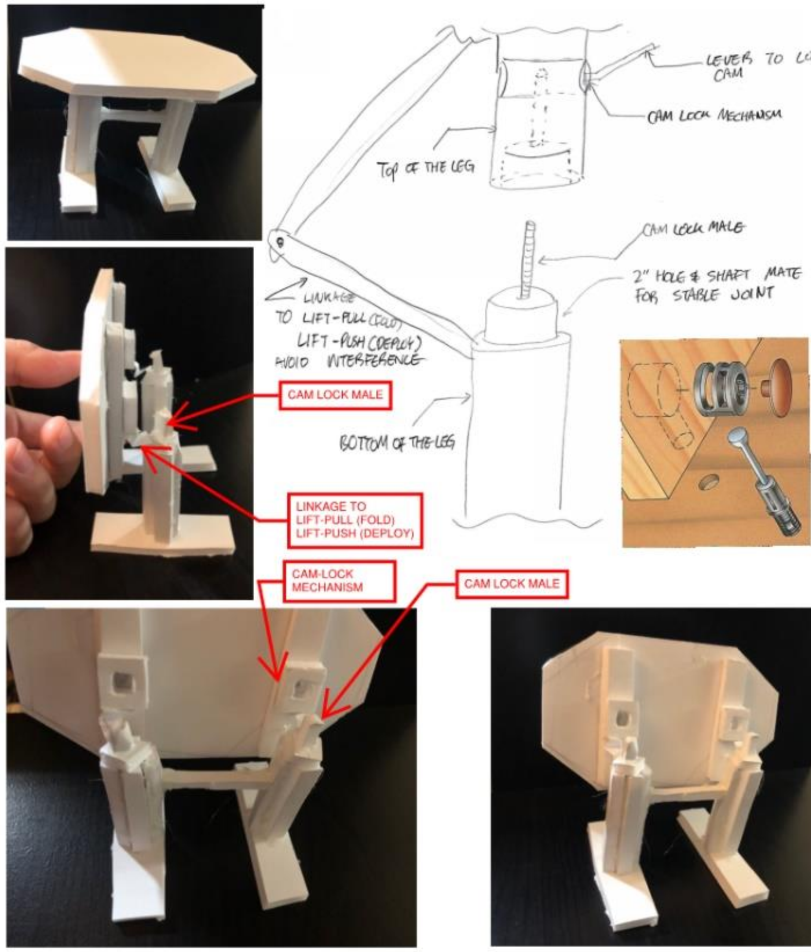


Figure 20: Hex Table Folding Cam-Lock Mechanism (Hinge Prototype)

We also created a hinge prototype (Figure 20), which provides a general fold-and-lock capability to the table prototypes similar to Figure 15 and Figure 16, to accommodate multiple concept prototypes that might need the folding capability. A cam locking function provides a wobble-free mating between the legs and the tabletop. The male cam lock, attached to the leg side, will be engaged with the female of the cam lock, attached to the tabletop side, and be tightened with a connected lever. However, extended mating length between the legs and the tabletop (cam lock male to the mating hole) requires a lift/lower motion to work properly, instead of a simple hinge motion. Thus, a linkage mechanism will need to be provided to make such movement to be possible.

4.4: Weighted Decision Matrix

Five total concept ideas were generated to be analyzed and compared using the weighted decision matrix. Similar to the Pugh matrix, the weighted decision matrix scored and ranked the five concept designs relative each other and to the datum design (the current Bonderson tables) but with much more detailed functions and its associated subfunctions. Functional criteria came from the QFD and from the sub-functions of the functional decomposition. To include each member's input evenly in making the final decision, we have averaged 4 different total scores from each individual. The decision matrix is shown in Appendix G:Weighted Decision Matrix.

The highest ranked concept prototype was Figure 15, the folding hex table. This idea scored high in the specification of ample room for personal workspace, improved communication and collaboration, straight edges for individuals to work at, and reconfigurability. Overall, the folding hex table concept design also scored higher than the baseline existing design, using a strengthened hinge design which we decided to be a more efficient mechanism compared to the mechanism from the datum design.

The second highest ranked concept prototype was Figure 17, the trapezoid base nesting table. This prototype received the second highest score for the nesting capability of this prototype, which stood out among the other prospective ideas, as well as This prototype received the second highest score for efficiently supporting the loads, having a strong leg/frame, and preventing wobbles.

After consulting with our advisor, we decided to prototype the top two ideas (Figure 15 and Figure 17, respectively) as we started to develop a more concrete design. Developing two designs simultaneously allowed us to continuously compare real-world performance that is difficult to capture otherwise; this allowed us to gain a better intuition for our final design. Figure 21 shows the CAD models for the hex and trapezoid base tables.

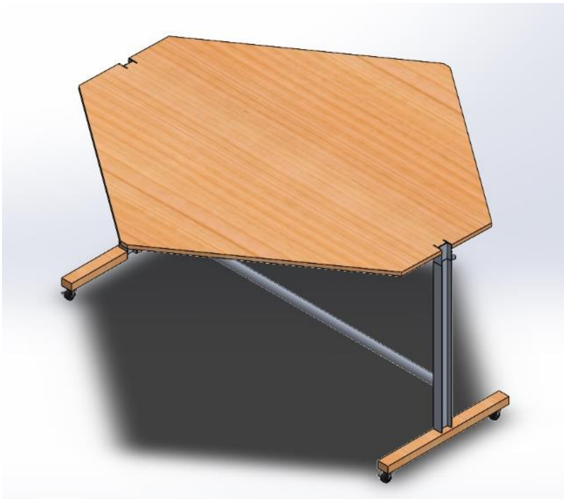


Figure 21: CAD concepts for our final designs to be prototyped.

4.5: Concept Designs

The following subsection presents our three concept prototypes: folding hexagonal tables sized for the individual and for a group as well as the trapezoidal base table. While the subsections dive into deeper detail,

Table 12 below presents the major design considerations.

Table 12: Summary of concept prototypes.

Concept Prototype	Major Features
Individual Folding Hex	• Sized for individual • Can be linked to form group table • Linkup in four or five-table configuration
Large Folding Hex	• Sized for group of four to five • Quick deployment with single hinge
Trapezoid Base Table	• Sized for four • Inserts into other tables for storage

4.5.1 Individual Folding Hex Table

Full scale prototypes of two versions of the hex folding tables design were built to test the user experience and to better understand the manufacturing process. The first version of the hex folding table was designed to have multiple table units combine as one collaborative table, and the second version of the hex folding table was designed as one large hexagonal tabletop with folding support legs.

Figure 22: Individual hex table, deployed and folded.

The small version of the hex table was created for individual use. The usability prototype was made from a 24” square stock plywood. The legs were made from ABS pipe and gave the table a height of about 27”, which classified the table as a category III table according to the BIFMA standards (Section 2.5: Regulations). The size of the tabletop did not allow for more than a couple notebook sized items and which shall be expanded for the future iterations. The tabletop folds down into a storage configuration as shown in Figure 22.

The individual tables were designed to be rearranged into groups of four or five. The hexagonal shape of the tabletop allowed the tables to fit together as a one unit. To demonstrate the grouping capability, cardboard tabletops were created to simulate the rearrangement. Figure 23 shows the two possible group configurations for this design.

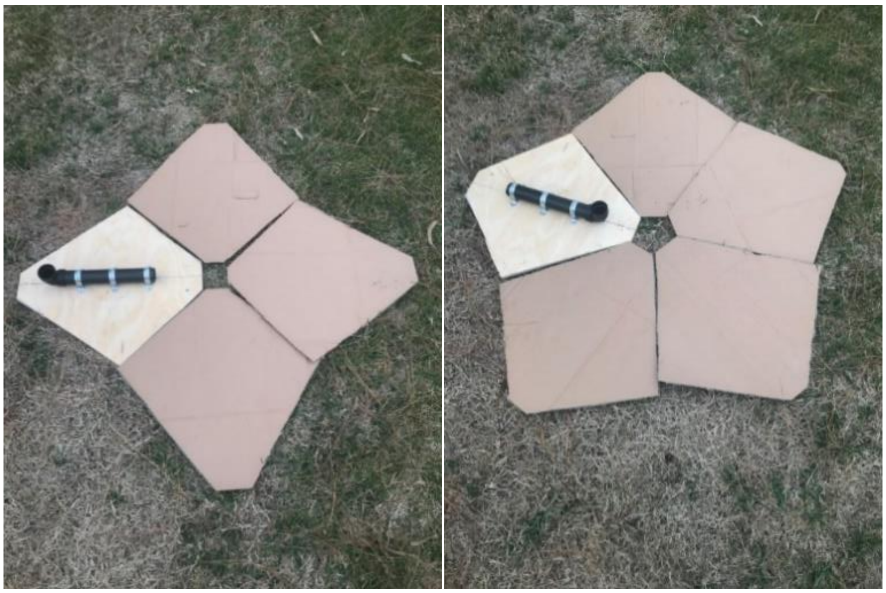


Figure 23: Tabletops in a Group of Four and Five

This version of the hex table functioned well as an individual desk but was too small for doing larger scale project work. Combining multiple tabletops did not give much of an advantage since the space from each tabletop was very limited. If multiple fully built tables were to be put together, the space occupied by the legs would not allow for them to be placed as close together as shown in the figures above. In addition, Table 13 below list the features of the big hex folding table usability prototype.

Table 13: Usability prototype features of the individual hex folding table

Parameter	Concept Prototype	Customer Requirement
Table Side Length	17 x 17 in. (made from 24in stock)	36 x 24 in. (Section 2.1.3)
Table Height	27 in.	30±2 in.
Base Material	ABS Pipe	n/a
Tabletop Material	15/32” in. Plywood	n/a
Hinge Design	PVC Collar	n/a
Deployment Time	5 sec.	30 sec.

4.5.2 Large Folding Hex Table

Figure 24: Big hex table full-scale usability prototype

The large-scale usability prototype of the big hex table was constructed out of 4x8' stock plywood with a thickness of 15/32". The tabletop was attached to the base with small metal hinges and a basic locking mechanism which prevented wobble and tipping of the tabletop once the table was deployed parallel to the floor. Figure 24 shows the prototype in positions for both usage and storage, a process which took about ten seconds to fold or deploy. We anticipate a longer folding and deploying time as the design develops, as the final design will be built out of significantly heavier materials.

The dimensions of the big hex tabletop, while limited by the size of the plywood available, were suitable for four-person usage with each of the long edges of the tabletop being 30" long. Our recommendation for the shape is to increase each edge to a length of 3' for a slightly more spacious individual workspace that will still allow for a compact storage and a collaborative working experience. The tabletop material would need to be a thicker wood that does not bend and has a much smoother surface finish. The wooden legs were constructed with screws and were reinforced with thin wooden supports that were nailed in into the feet and legs of the frame structure between. However, to enhance durability we would be using a more robust materials such as metal tubing.

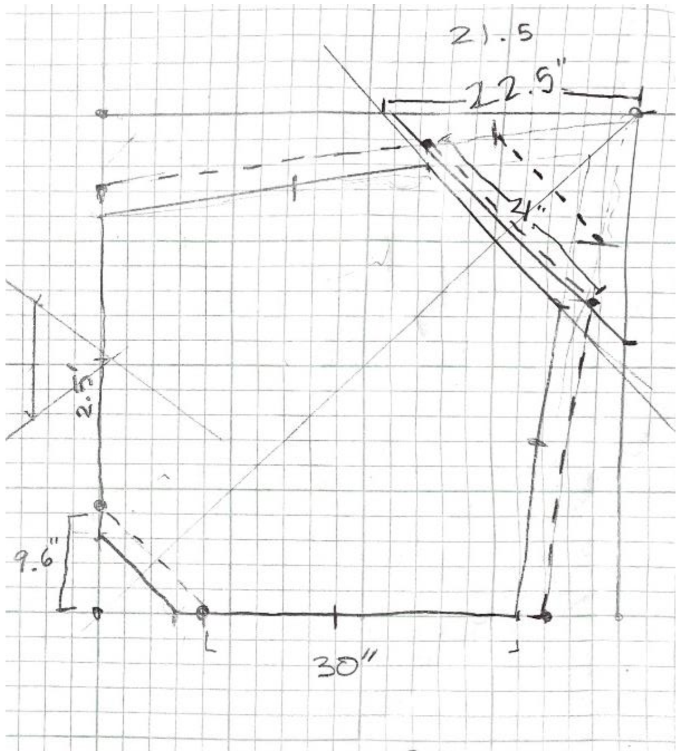


Figure 25: Dimension sketch layout of big hex folding table prototype

Figure 25 above shows the dimensions and cutline of the plywood tabletop for the big hex table. The table stood at 3' tall to allow students to work comfortably while standing or sitting on the stools. After sitting around the full-scale usability prototype, which was made with the dimensions shown above, we felt there were ample individual workspaces, and did not have any major concerns carrying over the proposed usability tabletop dimensions in proceeding with the design development of this concept prototype. Table 14 below list the features of the big hex folding table usability prototype.

Table 14: Usability prototype features of the big hex folding table

Parameter	Concept Prototype	Customer Requirement
Table Side Length	30 x 24 in. (for one user)	36 x 24 in. (Section 2.1.3)
Table Height	36 in.	30±2 in.
Base Material	2 x 4 in. wood stock	n/a
Tabletop Material	15/32" in. Plywood	n/a
Hinge Design	Door hinge + wooden stopper	n/a
Deployment Time	10 sec.	30 sec.

After conducting two analyses of the usability hex table prototypes, we decided to proceed with the big hex folding table prototype which has a better storage efficiency over the small hex folding table prototype. We created a CAD model of the large hex table to demonstrate how the design may evolve towards a final product. Figure 26 and Figure 27 show the table in deployed and storage configurations.

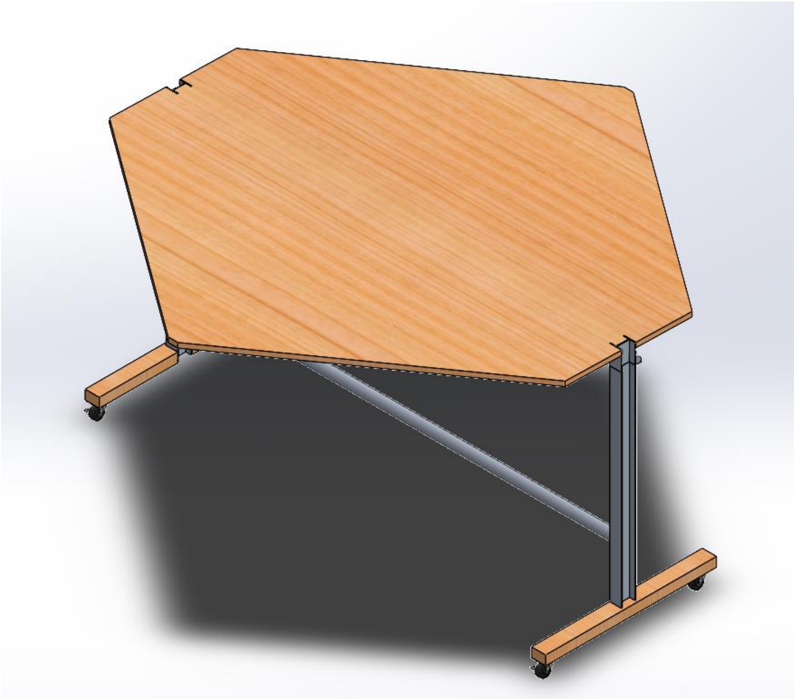


Figure 26: Folding Hex Table Isometric view, deployed configuration.

Figure 27: Folding Hex Table Isometric view, folded configuration.

The hexagonal shape of the tabletop will provide ample room for personal workspace and group collaboration with straight edges for individuals to work at, all in a reconfigurable design. 48” I-beams are used as the leg of the table for their wide availability and much higher stiffness than wood 2x4’s. Overall, the table will be 30” in height

Table 11) and use toggle latches and self-locking hinges which provide folding capability and a wobble-free deployment.

Detailed features of the concept design are shown below.

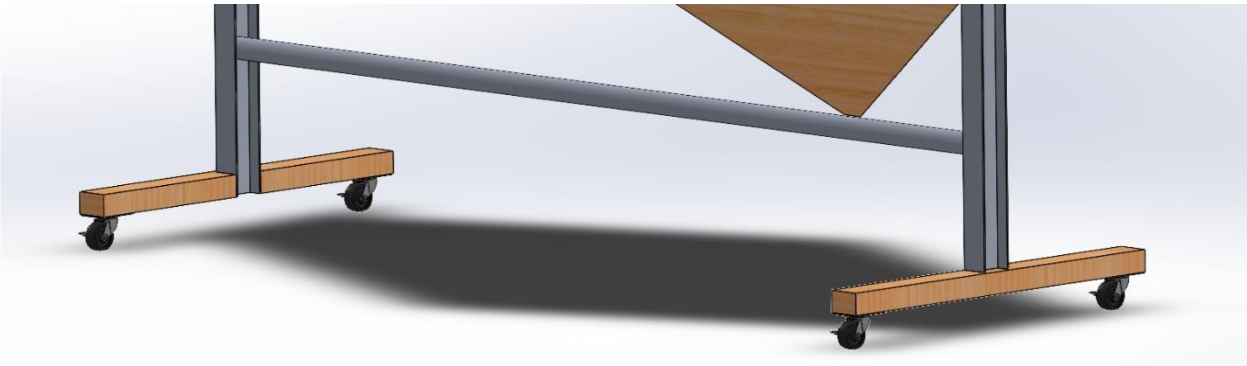


Figure 28: Folding Hex Table Bottom Support

Figure 28 shows the bottom of the table with caster wheels that aid in stowing the table quickly. They include a locking feature which prevents the table from moving around when desired. The wheels are placed and joined on extended wooden supports with bolts and nuts to prevent the table from tipping over when heavily loaded. Figure 29 shows the slot for the I-beam to attach to the table.

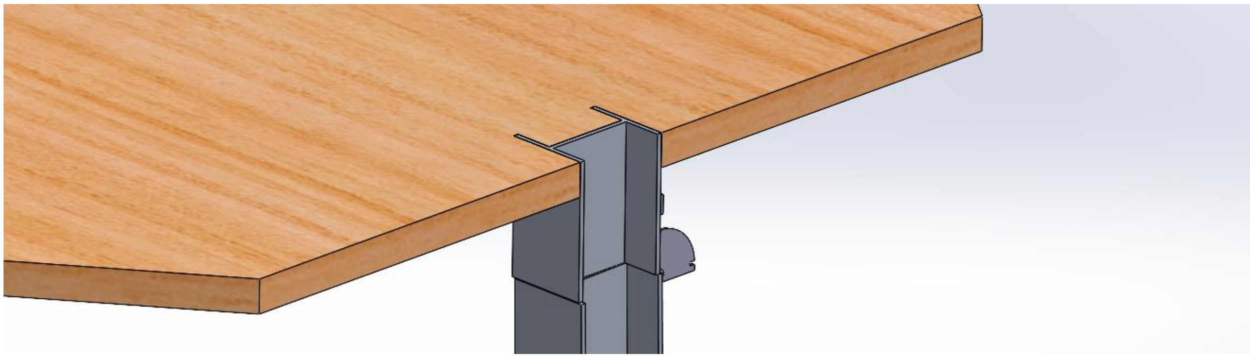


Figure 29: Folding Hex Table I-slotted fitting

Because we will have significantly limited access to the campus machine shop due to COVID-19, all the material joining of the design will be by bolts and nuts instead of welding. A weld-free design also simplifies the manufacturing process of the table. I-shaped slots will be made on the edges of the tabletop to perfectly fit the stock I-beam and to create a mate between the tabletop and the I-beam legs. Similarly, the bottom extended wooden supports will have I-shaped slots made to fit the stock I-beam legs and be joined with bolts and nuts. An aluminum supporting tube (between two I-beam legs) and an aluminum beam (between two I-beam legs, underneath the tabletop) will be installed with bolts and nuts to increase overall stiffness of the table and prevent bending of both I-beam legs and the tabletop.

Figure 30: Toggle latch design to be used in the Hex folding table (Manufacturer/Part TBD)

Figure 31: 90-180-degree self-locking hinges to be used in the Hex folding table (Manufacturer/Part TBD)

We also had to improvise to emulate the initial folding mechanism concept design (Figure 20) using only the off-the-shelf items to avoid complicated manufacturing. The cam-locking mechanism, introduced in Figure 20, has been substituted with a toggle-latch to provide a tight fit between the mating surfaces to prevent wobbliness, and the self-locking hinges are placed to replicate the feature of the linkage mechanism by providing folding functionality of the tabletop. Figure 30 above shows a typical toggle latch, and Figure 31 shows a self-locking hinge.

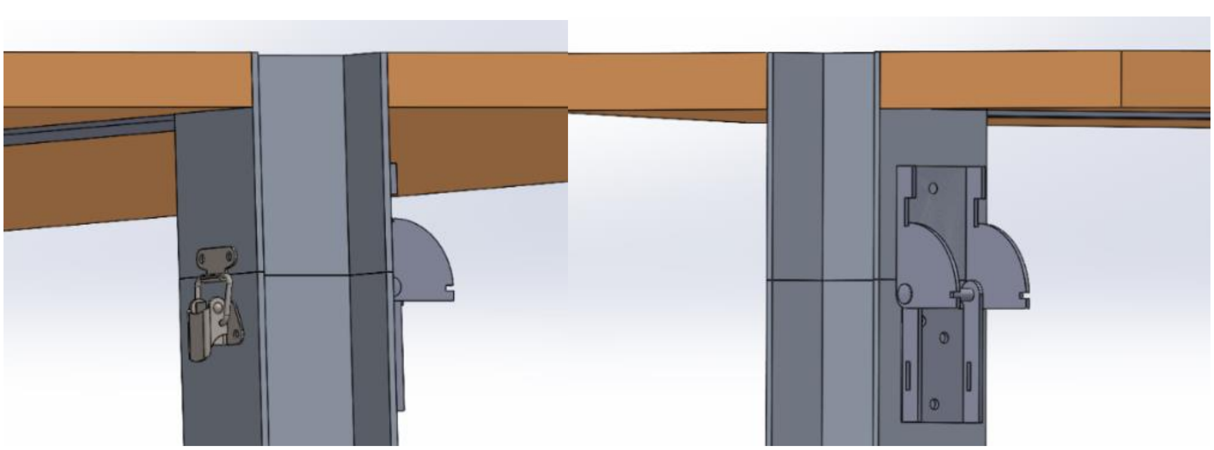


Figure 32: Folding Hex Table toggle latch and self-locking hinge

A toggle latch and a self-locking hinge are installed on each side of the flat surfaces of I-beam table legs with applied fasteners. In the deployed configuration, the self-locking hinge will be in a 180° locking position and the toggle latch will be locked.

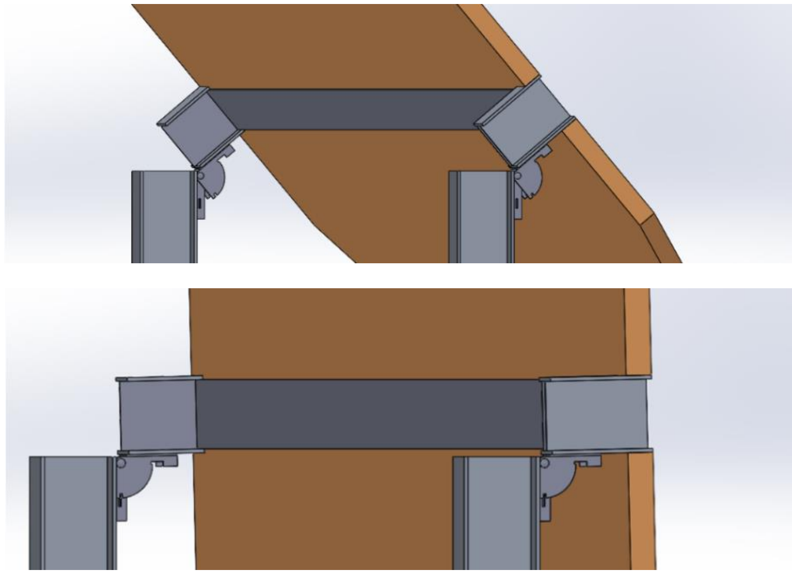


Figure 33: Folding Hex Table folding process

When the table is in folding configuration, the self-locking hinge will be at 90° and the toggle latch will be released. Figure 32 and Figure 33 above show the folding action of the concept.

Max loading and tipping automated calculators of the hex table will be developed progressively towards the critical design phase to make sure the design meets the engineering constraints, as the specific material properties (Young's modulus, Moment of Inertia from cross-sectional dimensions, etc.) have yet to be finalized. If the design is found to be insufficient to meet the stresses, extra supports will be added.

4.5.3 Trapezoid Base Table

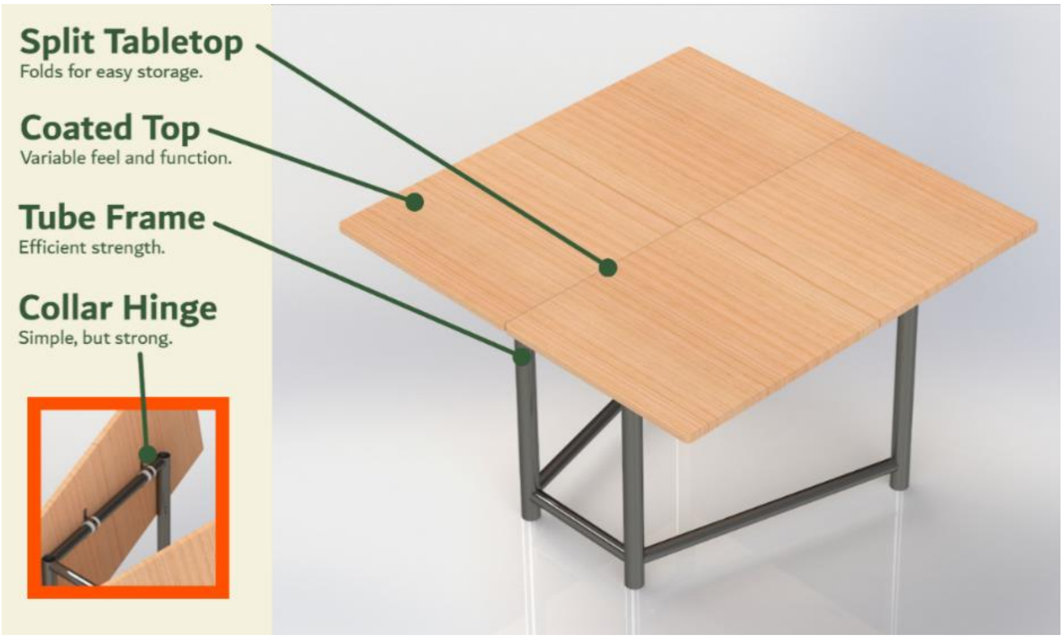


Figure 34: Isometric view, labelled.

The trapezoid table concept design shown in Figure 34 features a split tabletop that folds over a 30° trapezoid-shaped base, sized to support four people. This table is designed to nest in its folded configuration, with a minimum of moving parts for mechanical simplicity and cost considerations. Figure 35 below shows the concept prototype, folded.

Figure 35: Concept prototype built from ABS piping and plywood.

Our concept prototype was designed to test overall usability. Therefore, we captured the folding/locking actions of the table in a 1:1 scale. The prototype design has a 48” square tabletop driven by our initial spacing from Section 2.1.3 As seen in Figure 36, it is not large enough to support four people; two people have trouble getting adequate space when seated adjacent. Our goal was to fit a laptop, notebook, textbook, and writing utensils for each person. The final tabletop dimension will likely be 60" square to fit our use case defined in Section 2.1.3 (a 36" x 24" footprint per person). The prototype is 31" tall, which is the higher end of the BIFMA standards (see Section 2.5). Based on the usage test, the final design will be no higher than 30 inches.

Figure 36: Test usage of the 4-person table.

Built from ABS pipe and 15/32" plywood, our prototype is lightweight but not stiff enough for general usage. The open base shape requires a much stiffer material to maintain rigidity (the ABS base can flex a few degrees). A metal construction is more desirable in this regard. Furthermore, the tabletop tends to flex under corner loads over 15 lbs., so thicker plywood is necessary.

The prototype tabletops lock into place with a barrel bolt assembly commonly seen on residential fence gates. We used a similar system, but the table's low stiffness led to excessive slop, rendering the bolt assembly less effective. A different latch mechanism will yield better results, such as a compression latch or other device that grips the parts together. Table 15 below captures the overall architecture of the prototype and the proposed final design.

Table 15: Proposed final design geometry and materials based on the concept prototype.

Parameter	Concept Prototype	Final Design
Table Side Length	48 in.	60 in.
Table Height	31 in.	< 30 in.
Base Angle	30°	> 35°
Base Material	ABS Pipe	Aluminum EMT conduit
Tabletop Material	15/32" in. Plywood	> 1 in. plywood or composite
Hinge Design	PVC Collar	SAME
Tabletop Locking	Barrel Bolt	Compression latch or longer bar

Figure 37 below demonstrates how the base angle was selected. A base angle (black lines) of 30 degrees produces a stack space of 3cm (1.2in.) for an overall nesting efficiency of 60%. If the base angle is too small, then nesting efficiency drops. If the base angle is too large (90° is extreme), then the table is unstable. Once the angles were mocked up, we chose a 30° base angle as a combination of stability and stacking efficiency.

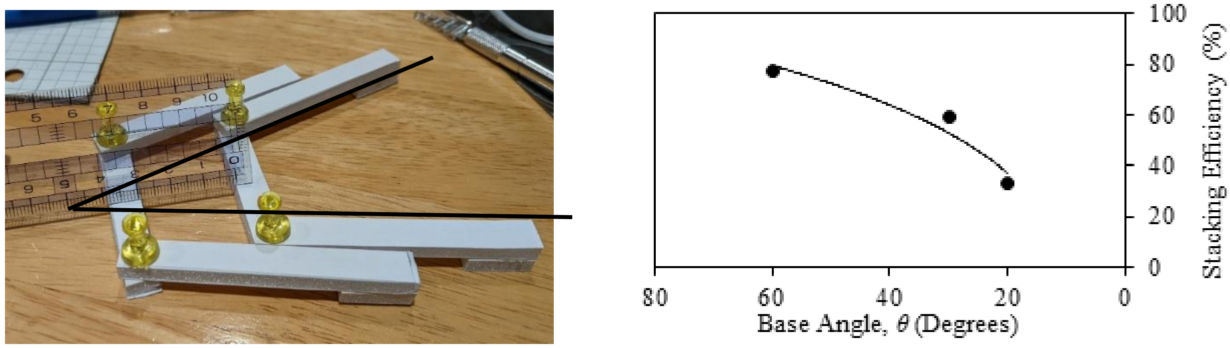


Figure 37: Variable-angle base mockup to test stacking efficiency pre-concept prototype.

We conducted a new stacking efficiency study in Solidworks as a function of tabletop thickness. The result is summarized in Figure 38 below; tabletop thickness (and pipe diameter) are linearly correlated with efficiency. To meet our initial efficiency goal in (stacking efficiency of 75%), the tabletops would have to be extremely thin, and the base angle would need to be very large.

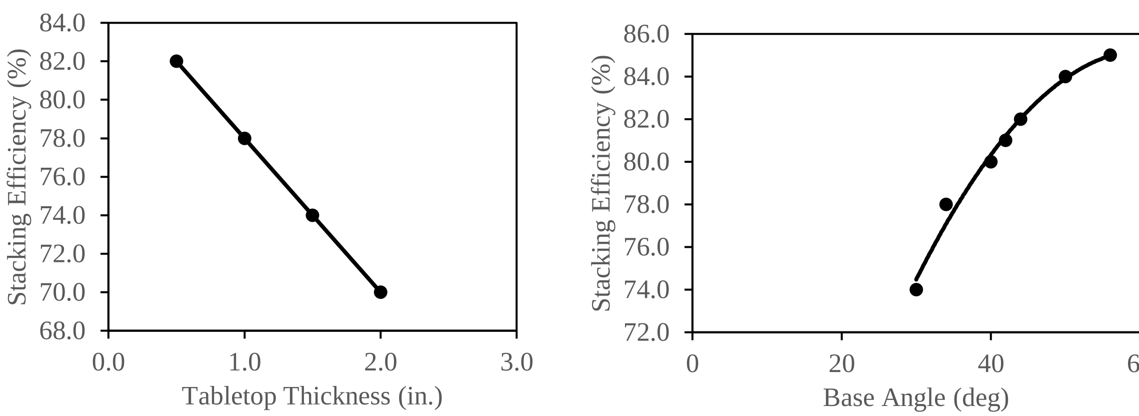


Figure 38: Stacking efficiency model based on prototype.

We also conducted simplified calculations to derive a relation between the weight of the table assembly to the maximum tipping load the table can withstand (applied at the tip of the front side of the table). The tip of the table on the front side has the biggest distance between the edge of the tabletop and the supporting legs, which creates the most vulnerable region to tip over the table when a concentrated load is applied. From the calculation, we have concluded that the current configuration of the trapezoid nesting table (30° nesting angle) and an approximated weight of 150 lbs., shall withstand a concentrated tipping load of 73 lbs.; this calculation is attached in Appendix H:Concept Prototype Analysis. However, our engineering specification (

Table 11) states that the table shall withstand a tipping load of 125 lbs. To increase the maximum tipping load of the table to our demand, additional weight shall be introduced to the current assembly, as the maximum tipping load is linearly proportional to the weight of the table. Table weight will be finalized in CDR phase as we finalize the materials for all the components. Also, load calculators for both the tabletops and the supports will be developed to make sure the design meets the engineering constraints listed in

Table **11**, as the specific material properties (Young's modulus, Moment of Inertia from cross-sectional dimensions, etc.) are yet to be finalized.

The method of attachment between the PVC collar and the tabletop are still undefined but will likely use a PVC pipe bracket or similar component from sheet metal.

4.6: Final Concept Recommendation

We utilized the extra time over the winter break to dive in and design three separate concept prototypes in detail. Per our sponsor's request, we are providing our engineering opinion to decide which design shall be chosen to develop further as a critical design and which design shall be spared as a back-up design. To make this judgement, we have decided to list the potential failure factors of both designs.

Potential failure factors of the hex folding table design:

- Narrow mating surface of the I-beam (0.15-inch thickness) may not be enough for the legs to properly connect. Mating surface may wear down due to fatigue as well, affecting the level of the tabletop to tilt in certain angle.
- Deployment of the table solely depends on the 90-180-degree self-locking hinges. Wobbliness of the table is expected if the build quality of these hinges is not satisfactory to support the table.
- Manufacturing of custom dimensions for the tabletop may be out of the price-range for this product for reproduction in which case the design would require a square cut instead. This would cause the table to lose some of its unique functions and may require a different method of attachment between the base and the tabletop.

Potential failure factors of the trapezoid nesting table design:

- Large pinch point as table comes together.
- The tipping calculations indicate a heavy table (>100lbs) is needed to keep from tipping.
- Trapezoid design may not meet original stacking requirements.

Even though the weighted decision matrix ranked the hex folding table prototype higher than the trapezoid nesting table prototype, the trapezoid table became a more attractive design to us over the hex folding table throughout the detailed final concept design development process. Major reasons for this decision were:

1. Trapezoid nesting table design is a bigger departure from the existing tables, helping to define our product as an upgrade rather than a similar product.

2. Many of the user survey results demanded rectangular shape tabletops as their preferable collaboration table.
3. Efficient nesting feature of the trapezoid table design.
4. The four hinge points provide a more distributed support for the table, making it more durable and inherently less prone to wobble than the hex table’s base design.

Thus, we propose the **Trapezoid Nesting Table** to be our final concept to move forward into critical design review.

5.0: Final Design

Our approach to this design challenge is a split-top folding table with a trapezoidal frame. The tabletop is a modified version of a lightweight composite product from IKEA, while the frame is a steel tube weldment. The tabletops pivot and slide along custom ultra-high-molecular-weight polyethylene (UHMWPE) hinge assemblies, and the table rests on caster wheels so the table can be moved easily. Figure 39 below shows two (2) fully built verification prototypes of the final design.

Figure 39: Fully built verification table prototypes.

5.1: Tabletop Design

The tabletop subassembly provides the main interactive component between user and product: it deploys flat to enable group and individual work and rotates into a vertical position for storage. We expect this articulation to be performed several times a day during the work week.

The subsystem revolves around two lightly modified IKEA tabletops. The dimensions of the two identical tabletops used are 55.126” x 23.625” x 1.375”, model name ‘LAGKAPTEN’. This dimension of tabletop accommodates the individual workspace (approximately 36” x 24”) as per our analysis in Section 2.1: User/Customer Research, and also accommodates workspace of four (4) people when two tabletops are placed side by side. IKEA’s reputation for product longevity alleviates concern of premature wear. The tabletops are a sandwich panel style composite, with two plates of particleboard bonded to a paper hex core. The top and side surfaces are coated with plastic material while the bottom surface is not.

Hinge assemblies are mounted to the tabletop using the drywall anchors bolstered with adhesive. This hardware both increases mechanical strength and enables serviceability: wood screws alone would be more economical, but if a repair required access to the hinge bushings, the servicer would have to remove wood screws threaded directly in the tabletop. Wood screws cannot maintain their grip when threaded into the same hole twice, so a new tabletop would be needed after such a repair. Hardware to be used for this purpose is explained in detail below.

Compatibilities for several anchoring hardware to the IKEA LAGKAPTEN tabletop were tested and documented in Appendix I:Hardware Compatibility Test Report. To explain the compatibility testing procedure, a weight of 10 lb. was dropped from a height of 2.5 ft to cause an axial impact load on the hardware installed on the tabletop The test passed using only one (1) set of hardware. In the final design, 12 sets of hardware in combination fasten one tabletop to the frame, thus the actual mating will be twelve (12) times more rigid than the testing environment where only one set of hardware combination was tested. We believe the above impact load case chosen for the testing is well above the necessary load bearing case for a single hardware and is suitable to simulate a worst-case motion where a user might snatch open the tabletop and hit the frame while undergoing the folding process.

In addition to the drop-weight test, a creep test of hanging the tabletop was conducted by applying continuous tensile and axial loads on the anchoring hardware combinations. With a string, a single screw eye was tied and hanged on a bar to bear the whole load of a tabletop in the air, which weighs around 20 lbs. Lastly, a destructive test was performed to destroy and extract the hardware from the tabletop by hitting the screw eye with a mallet and taking it out using pliers. Each hardware combination was ranked using the results of the destructive test based on the effort required to destroy and extract the hardware.

After conducting the above series of tests, the most durable combination of hardware was chosen to be the EZ Anchor hollow door & drywall anchor enhanced with Gorilla super glue adhesive. This anchor was installed on the joining locations for the hinge brackets, as well as for the compression latches on the side of the tabletops. Figure 40 shows the selected anchoring hardware installed on the tabletop surface below.

Figure 40: EZ Anchor hollow door & drywall anchor installed.

The initial phase design consisted of two pieces of hardware to install a single hinge subassembly on the tabletop. To provide an even more sturdy connection and throughout the design changes, we provided more screws and anchoring hardware to the installation as mentioned above. This extra hardware enhances the connection widening the surface area of the hinge bracket where it meets parallel to the bottom side of the tabletop, which will provide more area for extra screws. This addition diminishes the concern of using screwing hardware on the paper-filled table by splitting up the load bearing with the addition of hardware.

5.1.1 Tabletop Joining Slots and Compression Latches

The joining assembly interlocks the two tabletops to better resist the bending moments when the tabletop is deployed, guarding against accidental collapse. By joining together, the tables can act as one unit instead of two individual tables.

Three different methods of joining the tables were compared to find the best design to incorporate into our table. The designs were tested on two criteria. The simplicity of the design was tested to determine how intuitive the mechanism was to operate. A design that makes the table joining process easier and faster was preferred. In addition, the tables were subjected to a load at their midpoint along the seam. The deflections due to the load of the three designs were compared to determine a relative ranking.

The first design was an interlocking shelf mechanism shown in Figure 41. The tabletop on the left has a horizontal extension on the bottom with a vertical protrusion on the end that runs along the seam. The tabletop on the right has similar extensions that are mirrored to fit into the space of the left tabletop.

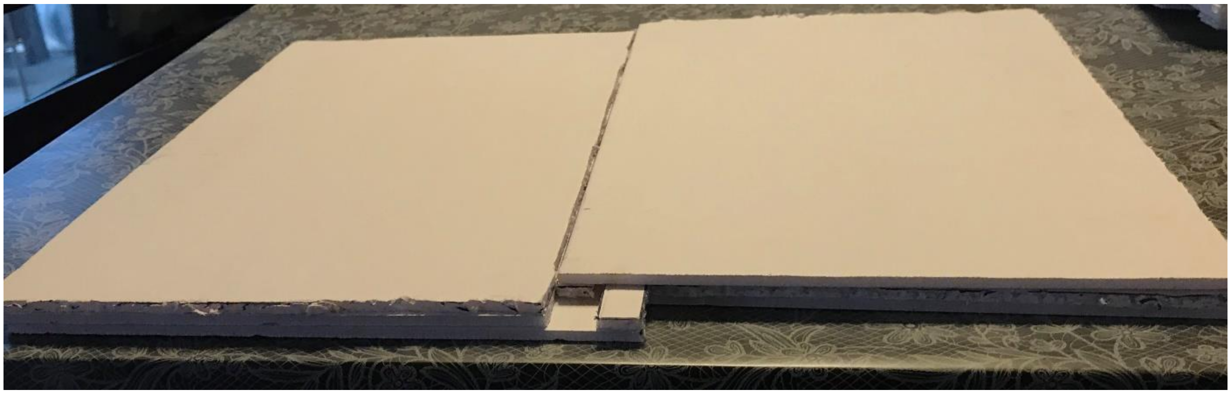


Figure 41: Interlocking Shelf

The next design is a tongue and groove shown in Figure 42. The tabletop on the left has a horizontal extension in the middle of its right side. The tabletop on the right has a grove on its left side that the other table can slot into.

Figure 42: Tongue and Groove

The final design works using staggered interlocking teeth as shown in Figure 43. The tabletops have matching cuts and extensions that come together like a puzzle piece. The two layers of teeth give it the stagger that helps hold the tabletops together.

Figure 43: Staggered Teeth

From our testing we found that the interlocking shelf design was the easiest and faster to operate but deflected the most. The staggered teeth design deflected the least, but the teeth were difficult to line up correctly. We decided to use the tongue and groove design because it had a good balance between resistance to deflection from load and simplicity in joining.

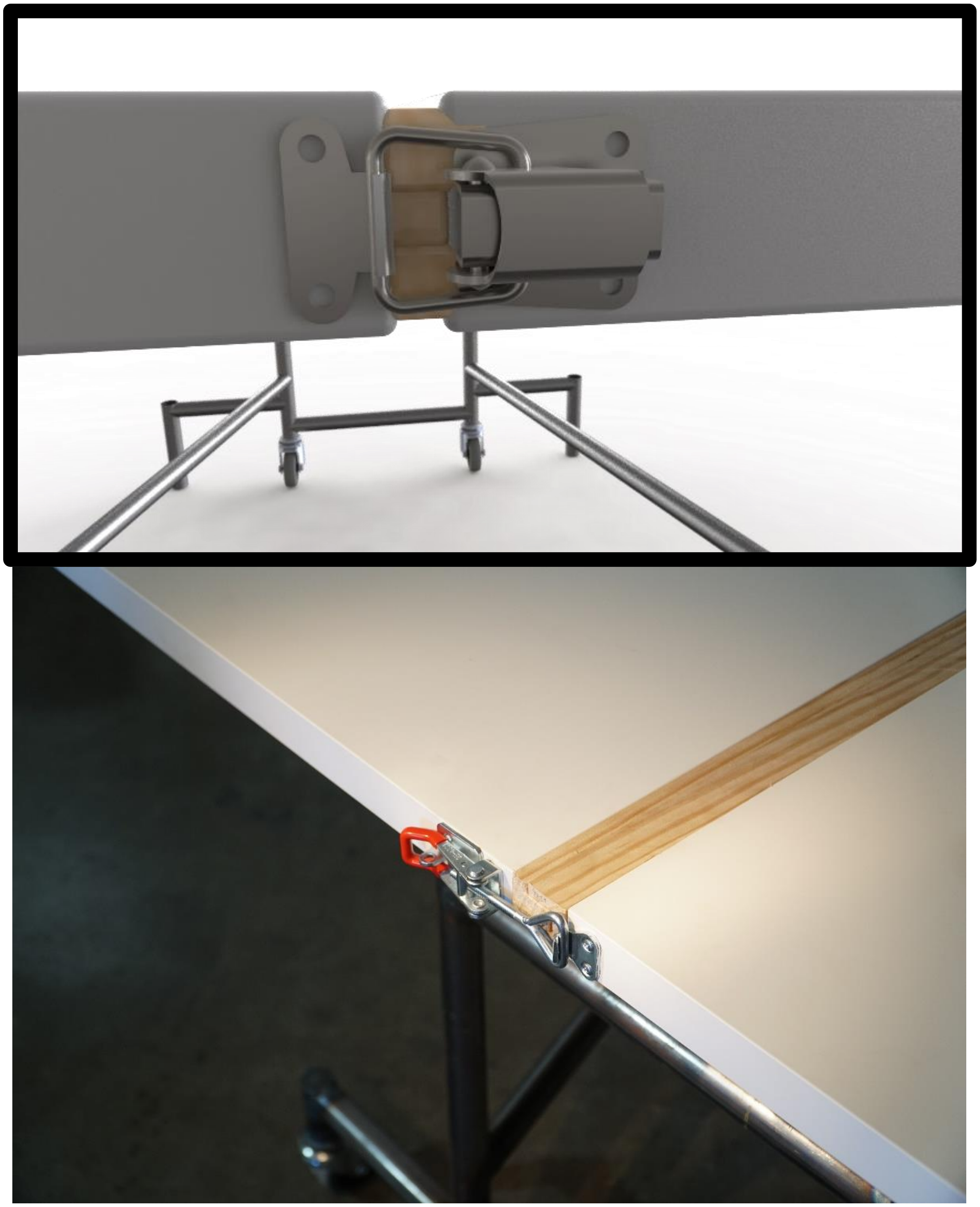


Figure 44:
Top – CAD model of tongue/groove and compression latch.
Bottom – Installed tongue/groove and compression latch on verification prototype.

To hold the joining assembly in place, we installed a compression latch on the sides of the table. This will aid the joining slots in bearing the loads. Figure 44 above shows the position of the latch; the tongue and groove are visible behind the latch. The latch model depicted above is not the actual latch installed on the verification prototype but provides the same compression – joining function.

5.2: Hinge Design

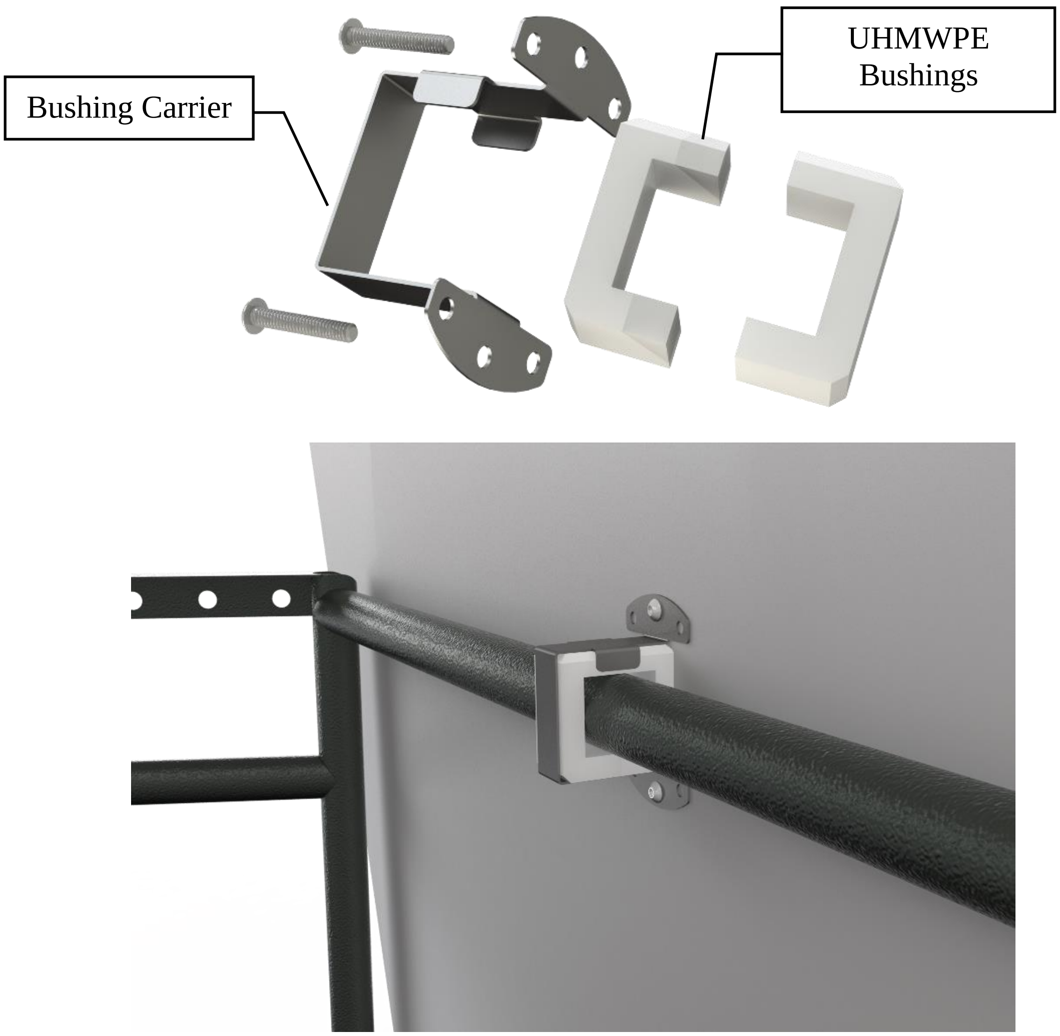


Figure 45:
Top – Exploded CAD model hinge assembly.
Bottom – Installed hinge assembly on tabletop.

The hinge assembly shown in Figure 45 above allows the tabletop to rotate and will undergo cyclic wear every time the table is deployed or stowed. The hinge is designed with two slotted UHMWPE blocks acting as bushings, retained by a simple sheet metal part. This design is an update from the concept prototype hinge, which was made from only steel plates without an extra bushing material.

The slot dimensions are by far the most important part of the design; the table's tendency to wobble was heavily affected by the slop between the hinge and frame pipe. Testing several different nominal slot dimensions showed that a zero fit between pipe and bushing eliminated slop while allowing for free rotation and providing a low level of resistance to sliding through the expected life of the table. More detailed test results can be found in Appendix K:Hinge Test Report and also in verification chapter.

As mentioned earlier in the anchor hardware explanation, more anchors (hardware) were implemented into the hinge design so that the load can be further spread out in the tabletop which is shown in the model of an updated bushing carrier having three holes on each side.

5.3: Frame Design

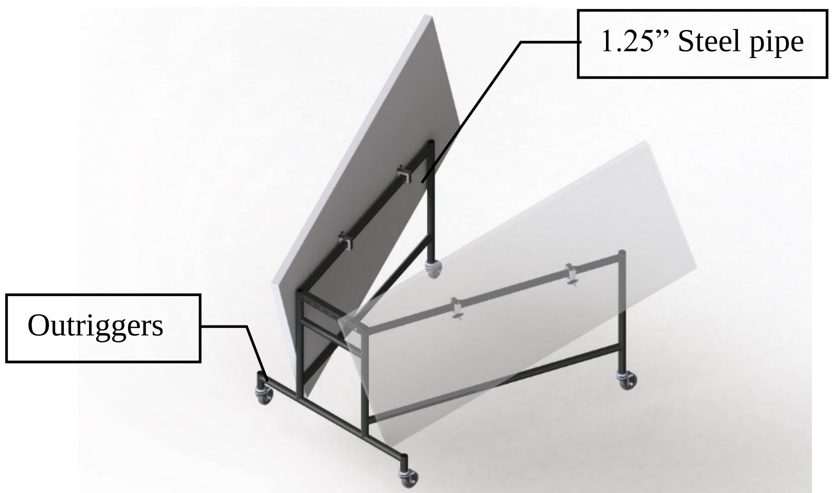


Figure 46: Frame subassembly.

The frame, shown above in Figure 46, is a weldment of 1.25” OD 1010 steel pipes. It provides a stable base for the tabletop to stand on and provides the nesting feature for the table. Casters on the feet allow for smooth movement, and use a standard lock when work is being done. This pipe thickness provides a good visual balance between the frame and tabletop. 1.5” and 2” pipes were considered but the larger size creates a visual imbalance in the table, and there is a negligible visual but significant cost difference associated with moving to 1.5” piping. These pipes are 25% larger in diameter than the pipes used on the current tables in Bonderson, and we have performed basic bending analyses on these pipes to make sure they are safe to use. Our loading calculation of the pipe in Appendix L:Tube Bending Calculations shows that our longest beam can hold a 290lb (accounting for only the frame assembly) point load at the center before yielding. This simplified load calculation was performed on our longest pipe case which is 47” and the load was assumed to be applied on the middle of the pipe which is supported on both ends to create bending and proves that the structural integrity of the steel pipe material will not yield even for pipe sections that are long.

According to the concept design geometry of the frame design, it was necessary to increase the overall weight of the table to withstand a 125 lb. tipping load (Table 11) at the edge of the table where it is the most vulnerable to make the table to tip over. Initially, pipes with 1.25” OD and 0.95” ID (0.3” thickness) was proposed to be used to increase the weight of the frame to resist tipping. In addition to having more expensive piping to increase the weight, the cavities of the pipe frame were proposed to be filled up with a filler material to provide even more weight gain to the whole assembly. The material to be used was going to be concrete with approximate density that is one-third of the steels. After conducting all the weight gains, the table assembly weight came out to be 121 lbs., which significantly diminished the table's mobility even with the installed caster wheels, and a different approach was necessary to resist tipping.

To overcome this matter, outriggers were designed to be attached to the front (narrow) side of the frame (shown in the figure above) in lieu of the weight-gain method to decrease the length of the horizontal moment arm that is paired with the vertical tipping load. Dimension of this outriggers is derived using the tipping calculator, shown in Appendix J:Table Tipping Calculations, which is based on the changing variables of the frame length, frame rear (wide) width, frame front width, and frame base angle. Optimization of the dimensions was done to achieve the best stacking efficiency, minimize the material usage (shortest pipes possible), and withstand the specified tipping load. While these components allow us to meet all of these requirements, we lose the ability to fit through a single standard door frame on wheels at this dimension. This adjustment will require us to shorten the leg lengths until this requirement is once again met.

From the sponsor feedback of the design presentation and moving forward to develop the verification prototype, we have decided to integrate the front caster wheels into the outriggers, rather than maintain the current design with outriggers and casters on the uprights. This eliminates the awkward positioning of the outriggers floating in the air and only making contact to the ground when the table is leaned against the load.

Geometry of the final frame design is shown in Table 16 below and is derived from the justifications explained and optimized with the results of the load calculation and tipping calculator (Appendix J:Table Tipping Calculations).

5.3.1 Bump Stop Subassembly

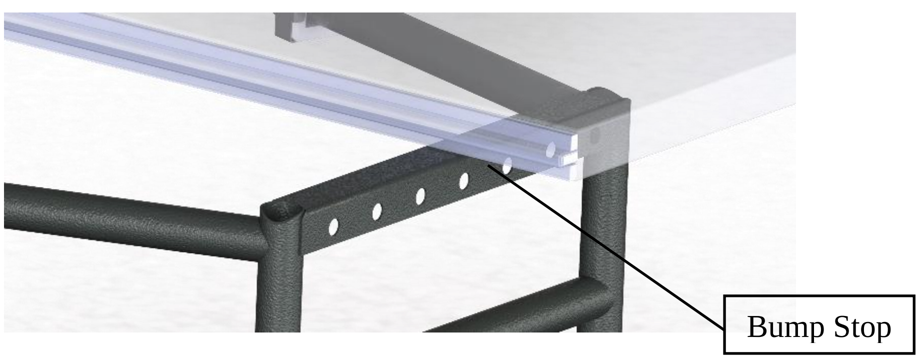


Figure 47: Bump stop subassembly.

The bump stop is a simple subassembly fixed to the frame to prevent over-rotation of the tabletops. Figure 47 above shows the most up-to-date bump stop design, which is made of steel plates, folded, and notched in size to fit between the space between the front side of the frame to be welded. The addition of the bump stop subassembly greatly improved the load support of the table in the deployed configuration and also provided more sturdy support of the tabletop subassemblies. Detailed dimensions of the bump stop subassembly can be found in Appendix P:Drawing Package.

5.4: Final Dimensions

Table 16 below readdresses the dimensions and the capable load bearings listed above in this section, as well the approximated total table assembly weight. To have a better understanding of the Frame dimension nomenclatures used, see Appendix J:Table Tipping Calculations, which explains the dimensions used.

Table 16: Final Prototype Dimensions and Properties

Tabletop	
Tabletop Catalog Name	IKEA LAGKAPTEN 55 X 24
Tabletop Construction Type	Particleboard shell with hex paper filling
Length [in]	55.126
Width [in]	23.625
Thickness [in]	1.375
Single Tabletop Approximated Weight [lb.]	21.2
Frame	
Base Angle [degrees]	36
Pipe Outer Diameter [in] (Thickness [in])	1.25 (0.065)
Front Width [in]	22.9
Rear Width [in]	47.0
Height [in]	26.2
Length [in]	45.0
Single Outrigger Length [in]	9.0
Calculated Frame Weight [lb.]	13.3
Maximum Tipping Load [lbf]	125
Maximum Load (Bending) [lbf]	290
Total	
Calculated Total Table Assembly Weight [lb.]	**55.8**

5.5: Safety, Maintenance and Repair

The trapezoid folding table is designed to be safe and intuitive to operate. Nevertheless, there are some important safety, maintenance, and repair considerations. We broke the table down by subsystem and identified different failure modes so we could consider all of the ways we would resolve and prevent these failures in the Failure Modes and Effects Analysis (FMEA) which is included in Appendix M:Failure Mode & Effect Analysis.

In order to determine areas of our design that may require modification to ensure user safety we completed Appendix N:Design Hazard Checklist and included the few potential hazards identified as failures to be remedied in the FMEA. Pinch points comprise much of the table's safety considerations. When the table is deployed, a major pinch point lies in between the previous version of the bump stop subassembly and tabletop halves as the tabletops swing down, as shown in the figure below. As the split tabletops slide together, they form a major pinch point. This issue has been addressed in our most up-to-date bump stop subassembly design, shown in Figure 47 above, with eliminated potential pinch point shown in Figure 48.

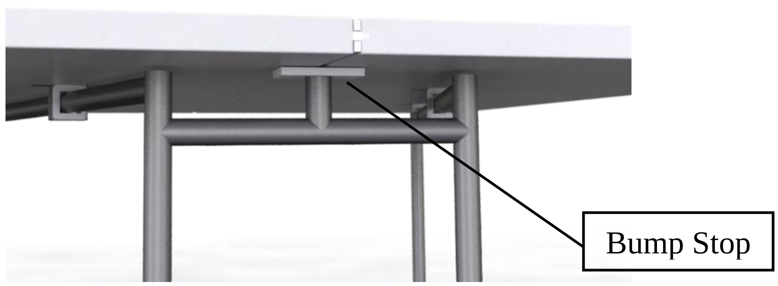


Figure 48: Initial phase bump stop subassembly design with pinch point.

We addressed another pinch point located between the split tabletops which is shown in Figure 49. One might think that the split tabletop's joining motion and the stowing pinch points should be obvious enough that a user will see the pinch point before they are hurt, but we listed this potential hazard in Appendix N:Design Hazard Checklist and installed a yellow and black stripe warning label across the tongue/groove feature for easier visualization.

Figure 49: Installed warning label across tongue/groove feature.

The table features a highly modular, serviceable design. If bushings wear out, they can be replaced easily because the drywall anchors permit screw removal and replacement. The tabletop halves can also be swapped out if one is damaged. Basic manual of operating the table assembly, including proper stacking, deploy/folding, required maintenance is described and listed in the attached Appendix T:User Manual.

5.6: Final Summary Cost (After manufacturing)

Figure 50: Front view of fully built verification table prototype.

The completed verification prototype is shown in Figure 50. The upper cost limit for our table we wanted to stay under was $350/unit. Table 17 below breaks down the major costs by subsystem we spent after manufacturing. The indented bill of materials includes more detail on the final parts and costs in Appendix O:Final Indented Bill of Materials.

Table 17: Summary final cost breakdown

Tabletop Subsystem	$78.32
Hinge Subsystem	$44.15
Frame Subsystem	$172.95
Casters	36.02
Welding	$0
Paint	$17.12
Parts Subtotal	$331.44
Total	**$348.56**

We manufactured the frame subsystem by welding the pipes ourselves to cut out the third-party welding price and chose to paint the frame instead of powder coating. We spent a total of $348.56 to build one (1) verification table prototype. The value of $348.56 is not an estimate from the cost analysis but the actual built cost.

6.0: Manufacturing

The section contains our manufacturing and assembly plans for the verification prototypes, as well as an introduction to the verification prototype result. Detailed drawings of the table components can be found in Appendix P:Drawing Package. All manufacturing was conducted between Cal Poly's two main M.E. machine shops: The Aero Hangar and Mustang '60. The designs and purchased components were selected to prioritize manufacturability by junior shop techs with knowledge of TIG welding and basic machining. Though the manufacturing is relatively straightforward, we estimate that the frame can be made in approximately 10-15 man-hours of work: most of this is devoted to weld prep and welding, with the milling operations for the bushings taking up another significant block of time.

6.1: Tabletop

6.1.1 Tabletop

The tabletop assembly is based around two LAGKAPTEN tabletops from IKEA (article number 404.608.15). Order in desired color, typ. white. The tongue and groove should be epoxied to each tabletop. The originally specified LINNMON tabletops (59x29.5") were unavailable, so LAGKAPTEN tabletops of dimension (55.125x23.625") are used instead. Both tabletops share the composite honeycomb paper filling sandwiched between fiberboard shells and are of similar thicknesses.

6.1.2 Tongue and Groove

The tongue and groove are wooden features fixed to the inside edge of each tabletop: their primary function is to resist the bending moments created when the table is weighted. Furthermore, the natural fitment provides a guide for the user as they deploy the table. The parts were made from a 1.5"x1.5"x8' beam of clear pine (Appendix P, drawing #'s 111200 and 111300). The tongue and groove were cut with a router, then epoxied to the tabletops.

6.2: Hinge Assembly

6.2.1 Square Bushing Half

The bushings are custom milled from UHMWPE. Any large endmill will be sufficient for this operation, but operators should ensure the end of the endmill is sharp to ensure good surface finish. After milling, a belt sander can make the necessary chamfers. Figure 51 shows a piece of stock being milled to size.

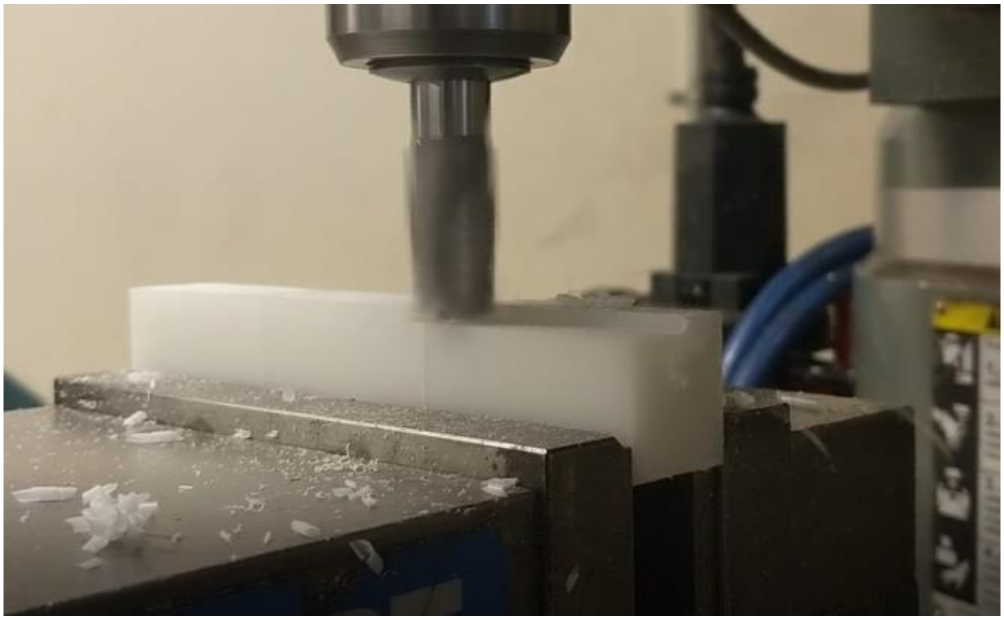


Figure 51: UHMWPE bushing milling process.

6.2.2 Bushing Carrier

The bushing carriers were cut out of 16ga mild steel using a waterjet. After removing surface rust, the carriers should be hammered into shape using a ball-peen hammer and appropriate fixturing. A vise is sufficient for most of the 90° bends but more creative fixturing may be required to fully bend the part into shape.

6.3: Frame Assembly

The frame is welded together from 16ga mild steel tubes. During manufacturing, a jig was devised to hold the frame parts at the correct angles for welding. Before the welding operation, the tubes were abraded with a wire wheel to remove oxides, then degreased with acetone. This process was even carried out on the inside of notched tubes to prevent weld bubbling.

The frame is made from six 6ft. sections of 1.25 in. OD x 16GA mild steel tubes. Figure 52 shows the cut list for each tube to produce enough parts for one table. The tubes should be cut with an abrasive saw to mitigate tearing risk with a toothed saw.

RAW LENGTH (in.)	72	RAW LENGTH (in.)	72	RAW LENGTH (in.)	72
Cross Tube	47	Outrigger Cross	33	Cross Tube	47
R Upright	24	F Cross	15		
		Outrigger Leg	3		
		Outrigger Leg	3		
EXCESS	1	EXCESS	18	EXCESS	25

RAW LENGTH (in.)	72	RAW LENGTH (in.)	72	RAW LENGTH (in.)	72
F Upright	22	Cross Tube	47	Cross Tube	47
F Upright	22				
R Upright	24				
EXCESS	4.5	EXCESS	25	EXCESS	25

Figure 52: Cut list for TransporTable frame. All dimensions in inches.

Each tube may be notched on one, both, or neither of its ends. A measuring tape and paint pen are sufficient to make these cuts as shown in Figure 53 below.

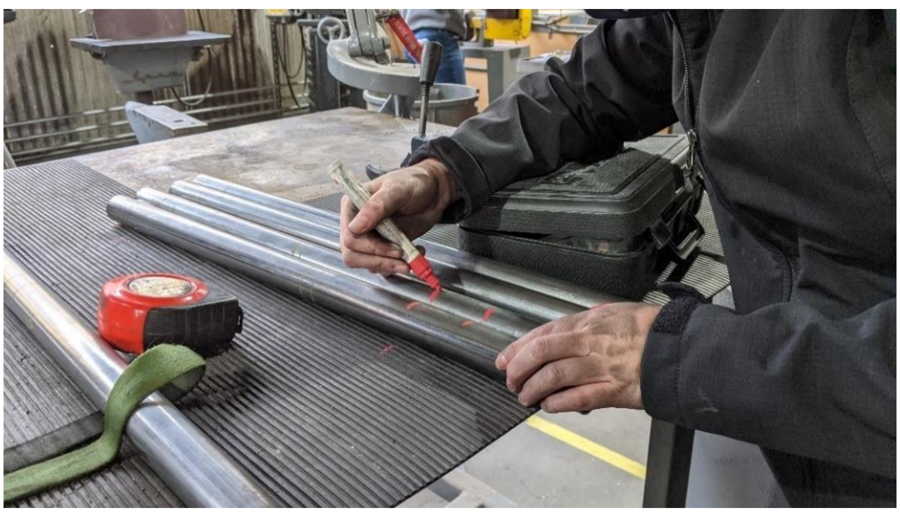


Figure 53: Steel tube sizing process.

Tubes notched at both ends (parallel 90° notches):

- F Cross (Qty: 1)
- Outrigger Cross (Qty: 1)
- Cross Tube (Qty: 4)

Tubes notched at one end:

- F Upright (Qty: 2)

Tubes not notched:

- R Upright (Qty: 2)
- Outrigger Leg (Qty: 2)

Figure 54 shows a 90° notch. Deburring was done using a bench grinder and hand file.

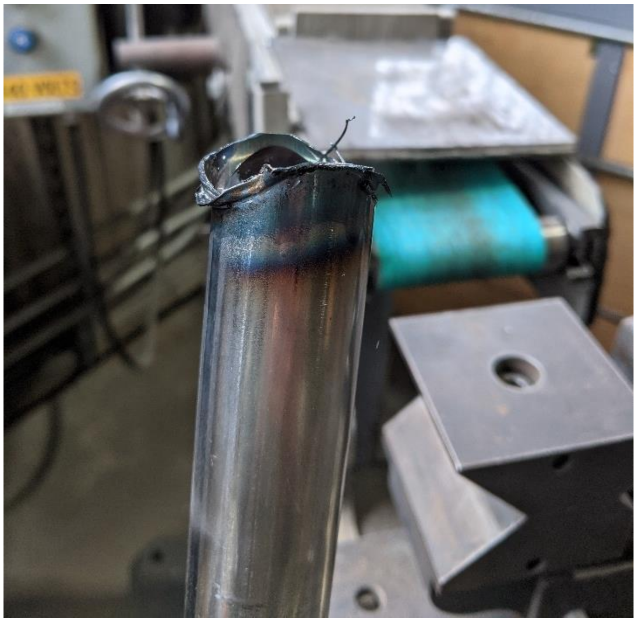


Figure 54: Example of notched steel tube for the frame assembly.

After the frame tubes were welded, the bump stop plate was waterjet then bent into shape using a press brake before being welded into the frame. The bumps stop can be seen in Figure 55.

Figure 55: Manufactured bump stop plate for the frame assembly.

Drawing 113000 specifies the proper angles and spacing of tubes to make the frame. Figure 56 show the usage of jig to properly weld the steel tube parts into the frame.

Figure 56: Snapshots of frame jig in the use of frame manufacturing.

Figure 57 below shows the frame welding results.

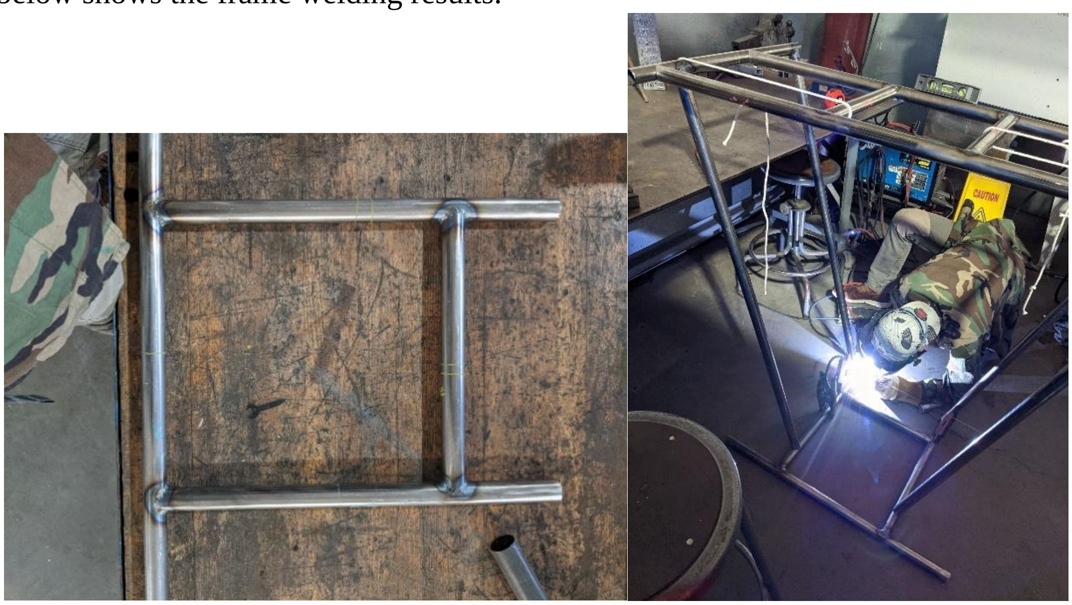


Figure 57: Snapshots of frame welding process.

6.4: Table Assembly

6.4.1 Hinge to tabletop

First, the tabletops' tongue and groove were pushed together. The bare frame was turned upside down on the tabletops, then the hinge assemblies were fitted to the tabletop as shown in Figure

58. After centering the frame and positioning the hinges, the pilot holes were marked and drilled as shown in Figure 59.

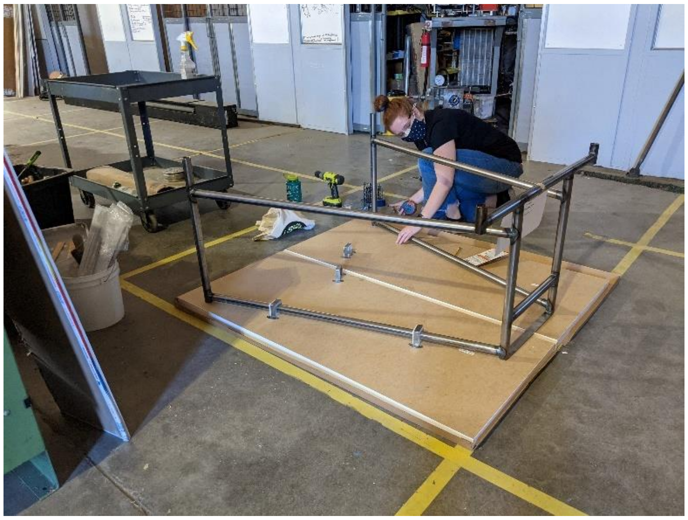


Figure 58: Hinge to tabletop assembly demonstration.

Figure 59: Locating the holes for wood anchors.

The wood anchors were installed, and the hinges were screwed into the anchors. After all four (4) hinges are properly installed to the tabletops, two people gently flip the table on its right side as shown in Figure 60.

Figure 60: Assembled transportable.

6.4.2 Compression Latches

After the tabletops were assembled, the compression latches were installed in a similar fashion to the hinges: the latch was positioned, then used as a jig to locate pilot holes for the anchors. The pilot holes should be drilled with a ¼" bit, then the plastic around the pilot hole should be cleared with a 3/8" drill to prevent deforming the surface when the anchor is installed.

Figure 61 below demonstrates the proper compression latch installed on the tabletop assemblies.

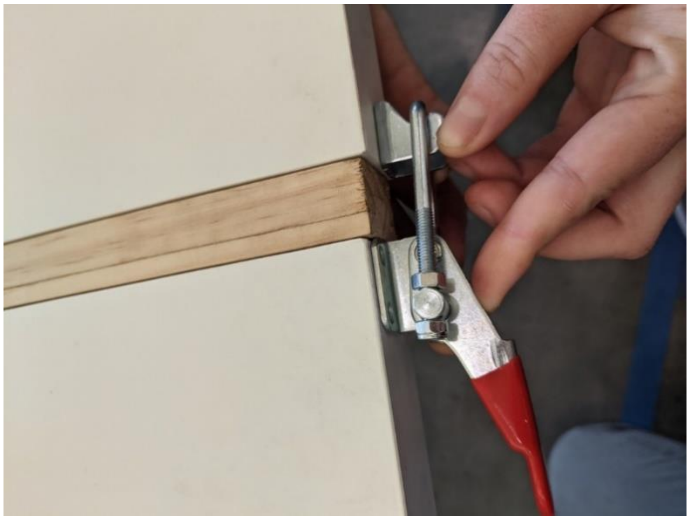


Figure 61: Compression latch install demonstration.

6.4.3 Caster Wheels

After the table is assembled, the casters are simply screwed into the frame mounts and hand tightened.

6.5: Challenges and Recommendations

Several manufacturing challenges exist: first, the frame must be welded carefully to ensure correct dimensions. The size, weight, and angles involved all lead to some awkward welding positions, so the welder must be creative in jigging to produce good quality work.

Next, the hinge brackets were difficult to maintain good tolerances. The imprecise nature of these parts led to highly unpredictable fitment in a place where fitment directly impacts the user experience. This problem led to a more rigorous development of tolerances covered in the design verification section.

Finally, the plastic siding around the tables' perimeters presented challenges when trying to install anchors. It is important to spot drill the area around any anchor to remove the plastic coating to prevent bunching and deformation around the anchor.

For future production of the design, we recommend a detailed redesign of the hinge assembly or implementing a quality control process due to the imprecision of the part manufacturing. Furthermore, we recommend further research into the tongue and groove design to add further strength to the table. If this table is to be taken to a large production run, we also recommend designing more ergonomic frame jigs.

More detailed information on manufacturing, including steps to manufacture each part, can be found in Appendix Q: Manufacturing Plan.

6.6: Final Budget Status

Parts were procured from a variety of different vendors. Purchasing in bulk or consolidating all purchases to fewer vendors would reduce the $348.56 price per table. A detailed budget report is located in Appendix V:Final Project Budget Sheet. Note that the budget sheet has two columns one labeled "Budget Transaction" and "Grant Transaction" The first column was for any purchases billed to the ME department budget. For this project we did not have any such purchases.

For our project we applied for and received a CP Connect grant for $1030.40. This was the estimated cost to build two tables including welding and powder coating. To help with manufacturing we also created a welding jig. Including the costs of the welding jig material and an additional table, the total expense was $666.06. We were under budget by $364.34. This is due to the omission of welding and powder coating costs as well as material being shared between the two tables. Because we did not spend all CP Connect funds, no purchases were ever charged to the ME department itself.

7.0: Design Verification

7.1: Overview

The design verification section explains how we tested our verification prototype to ensure it met all the specifications we identified. The requirements for each specification have been briefly identified in

Table 11 and are tabulated in detail in Appendix R:Design Verification Plan and Results; the tests that we will be discussing further in this section were designed to perform to these requirement levels. The design verification specifications to be met satisfy two main criteria: usability and durability. The tests outlined and conducted in this section are broken up into sections based on which type of specification they satisfy. Tests # 1 through 5 (listed in the Design verification plan and result appendix) and hardware compatibility tests were conducted and incorporated into the final design before CDR phase of the project. This section contains tests #6 through 13 from the design verification plan and result spread sheet.

7.2: Usability Specifications

The tests described in this section were conducted to prove that the design meets or exceeds all the requirements that are focused on user feel and comfort.

7.2.1 #7 Deploy stow Test

The first usability related test conducted was to verify the deploy and stow function to prove that each function can be efficiently performed according to our requirement (#7). To quantify this, we instructed a test population to perform the deploy function as well as the stow function seven (7) times each. We recorded the time taken for these exercises and determine what the average times were for the entire population as well as the maximum and minimum for each. Passing criteria include if 80% of the trials are completed in 30 seconds or less for deployment and 45 seconds or less for the stowing. This test can be performed in any space and requires only a stopwatch, a spreadsheet to record results, the finished verification prototype, and a diverse test population of at least ten people to perform the trials. See Appendix U for detailed Test #7 procedure.

The test was conducted with seven (7) sample users utilizing one (1) fully built verification prototype on a leveled ground per the test procedure. Average stow time of the samples was 33 seconds which passed the requirement; however, average deploy time was 34 seconds which did not pass the goal time of 30 seconds or less. Even though our expectation of the user being able to deploy the table in 30 seconds was not achieved from the average time measured for seven trials, 3 out of 7 trials were completed within 30 seconds and we believe this test result to be acceptable for what we anticipated. There is no further recommendation for deploy and stow efficiencies.

7.2.2 #12 Long-term usage Test

In order to ensure the satisfaction of the target population with the table during general usage, we outlined a "long-term usage" test to be conducted on our finished prototype (#12). For this test we gathered a test group of students from our target population (living in one household to ensure COVID-19 safety) to use the table for a period of at least one week for studying, collaboration, socialization, etc. Figure 62 shows two of our team members testing the table's usability. After this time period we provided a survey to the group to ensure that they experienced no significant discomfort, issues, or dissatisfaction during their table use. If any significant issues are brought to our attention, we sought to remedy these before recommending the table for use, but in the absence of negative feedback we were able to confidently recommend our design as a replacement for the tables in Bonderson 104 and Cal Poly or possibly elsewhere with significant interest. Most of the hazards we identified in Appendix N:Design Hazard Checklist are completely avoidable in the absence of user error. We outlined some long-term solutions such as warning labels and brightly color-coding pinch points to be assessed whether any of these issues arise during this long-term usage test. For detailed test procedure of test #12, see Appendix U:Test Procedures and Result Reports.

Figure 62: Team successfully having a lunch break on the verification table prototype.

We have decided to leave the third-party one weeklong usage test to be conducted to further develop the table for future improvements. However, throughout our 4-day span of internal usage test, we acknowledged the following observations:

1) Tabletop’s sliding feel across the frame heavily depends on the bushing carrier’s fit. To enhance this deficiency, we conducted test #13 statistical bushing carrier manufacturing test to derive an optimal dimension for the bushing carrier that houses the UHWMPE block bushing to provide a desirable fit to run across the steel frame smoothly. Our initial concept for test #13 was to derive the tolerance for the UHWMPE block bushing presuming that the fit would depend on the block bushing itself, but we were able to modify the testing to aim for the bushing carrier dimension instead.
2) Updated the bump stop subassembly from a T-shape to a bent sheet metal part which significantly improved the table’s stability when in deployed configuration.
3) Implemented anchor hardware found in Appendix I:Hardware Compatibility Test Report to install the compression latches on the side of the tabletops. The anchor did provide more sturdy connection for the table to take more loads.
4) Verified that the table frame layout does not interfere with the users’ legs when using the table sitting down on chairs.
5) Tongue/groove feature still permits slops in the table and would recommend upgrading the design of the feature or modify the manufacturing process to eliminate the existing slops by providing a tighter mating.

7.2.3 #6 Stacking Efficiency Test

The usability testing involved the nesting function of the table (#6). Our analysis allowed us to achieve a stacking efficiency of 78% which is an improvement from the 75% stacking efficiency that the Bonderson baseline tables meet. We assembled two (2) verification prototypes, shown in Figure 63, to verify that this calculation holds true with our final design and that the nesting action itself—which includes the movement of the table from one location to the designated storage and nesting location by a single operator—is feasible and can be achieved with no difficulty or conflicts. For detailed test procedures and results for test #6, see Appendix U.

Figure 63: Performing stacking efficiency test.

After measuring the stacking dimensions, which were defined as the "Maximum horizontal length of one table in fold configuration" and "Total horizontal length of two tables in folded configuration, stacked", and comparing them to the anticipated CAD model stacking dimensions, our verification prototype achieved less than 1% (0.57%) difference in the dimensions. A design stacking efficiency of 78% was achieved in the verification prototype; see the critical dimensions and the detailed result in Appendix U:

7.3: Durability Specifications

7.3.1 #13 Statistical bushing carrier manufacturing Test

To physically verify our final design, we performed three physical tests by building structural prototypes to verify the major design concerns we came up with from the preliminary concept design. These tests were performed to ensure that our hinge design worked without wobble or significant wear, our two tabletops joined with a flush mating surface, and our tabletops were properly fastened to the hinges using inserts that are bonded with superglue. The tests informed our design decisions leading up to this presentation and have been outlined in more detail in the Final Design justification section of this report in conjunction with our analysis.

While the hinges that were manufactured during the structural prototyping stage were assessed in-part based on the ease of performing rotating and sliding motions as well as the absence of wobble during use, we acknowledged that the wobbliness heavily depends on the dimensions of bushing carrier, which is the part made from a water-jetted and bent steel plate. If the bushing carrier did not provide a proper fit to house the bushings, the table tended to have more wobble. To prevent this from a mass-manufacturing point of view, we prepared a test to derive the tolerances of two (2) critical dimensions of the bushing carrier that most affect the fitting condition; these dimensions are displayed in Figure 64 below with the bushing carrier front view. Details of this test (#13) are described in Appendix U.

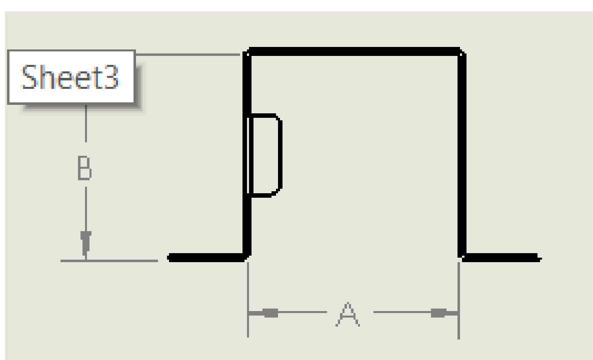


Figure 64: Critical dimensions (A and B) of bushing carrier to provide tolerances.

We manufactured nine (9) different bushing carriers which were able to provide the proper fitting to the table frame while eliminating wobble. By measuring the critical dimensions, A and B, shown in Figure 64, of the individual bushing carriers, we derived the tolerances for both dimensions using the uncertainty propagation method. Nominal and tolerance dimensions of the bushing carriers, as well as the hand calculation of the uncertainty propagation method are shown in test #13 in Appendix U.

The primary requirements for durability of the table design were proven with general testing criteria provided by the Business and Institutional Furniture Manufacturers Association (BIFMA). Testing the prototype to ensure that it passes these tests is essential to proving that the table is durable and robust, meaning it is safe to use.

7.3.2 #8 Tipping Test

The first of these durability tests is the BIFMA Tipping test (#8). For this test, the table was loaded with 125 lb. at the most extreme location (most likely to cause a tip) which in this case is the corner of the front end of the table. The test is based on Pass/No Pass criteria and the tipping calculations we did suggest that the prototype should pass the test by a narrow margin. The detailed procedure of test #8 is shown in Appendix U.

Figure 65: Loads being applied at the testing point on the table.

We placed the 125 lb. known load at the corner of the table, shown in Figure 65, where the frame is supported by only one of the outrigger legs and verified that the table withstood the load and did not tip over. However, approximately 5 degrees of tabletop deflection was observed mostly due to the imperfect fit of the tongue and grove feature that holds the tabletops together. The tabletop was not damaged but we would recommend upgrading the design or manufacturing method of the tongue and grove feature for future improvement, reiterating the recommendation from test #12.

7.3.3 #9 Concentrated Load Test

The next test performed was the BIFMA Weak Point Test (#9). We identified the center point of the rear edge of the table (along the seam where the two tables meet) to be the weak point. The tongue and groove connection as well as the latch assist in holding the table together but provide less support for a load than any other location on the table. Thus, they were the most likely to yield to a load and require additional reinforcement. At this identified weak point, the table must be able to withstand a 200lb load applied according to BIFMA's standards. This load case mimics a scenario where a user sits on the table at this particular spot, so it is important to ensure that our table meets this requirement for user safety. A detailed procedure of test #9 is shown in Appendix U.

Our results of the concentrated load test showed that the verification prototype can only withstand the vertical static load of 102 lb. We heard a cracking noise from the table after applying a load beyond 102 lb. as well as concerning levels of deflection of the tabletop. Based on the results of test #8 (table tipping test), we expected the table to be able to resist a load beyond 125 lb., but from the test #9 process we noticed that our tongue/grove feature between the tabletops is the weakest point of the table and is not capable of handling vertical loads. As a recommendation for the future improvement of the project, the table joining feature, as of now the tongue/groove, should be redesigned to better withstand the vertical load.

7.3.4 #10 Drop Test

The next test was the BIFMA drop test (#10). For our table, we chose to drop the table from a height of 2.4 inches which we believe to be a suitable for a table of this size and weight designed to be transported by rolling. This requirement, like the others outlined by BIFMA, uses Pass/No Pass criteria. The verification prototype was lifted by two people to the height of 2.4 inches, measured with a tape measure, and dropped. A detailed procedure of this test is shown in Appendix U. The table showed no visible damage and therefore there is no need for further development to address this test.

7.3.5 #11 Leg side Test

The last of the tests required for us to meet BIFMA's standards was the Side Load test, which involved the application of a 100lb force to each of the four table legs (applied parallel to the ground) while the other three legs are held static (Test #11). The test was to ensure that the legs did not yield to side loads such as these, which we might expect them to experience if someone or something were pressing against the table legs. The test required a system to apply a load of 100 lb. to the table but could be performed anywhere. The system used in the test included a load gauge, one person holding on to the table, and one person adding weight while holding the gauge. The gauge was attached to the leg being tested and the tester leaned back against the table to apply load. A calculated load of 100lb, measured using the gauge, was applied to each leg one at a time (while the rest of the table was supported by walls/held in place). The legs pass the test if no damage or yielding is observed as a result of the force applied. The detailed procedure of this test is shown in Appendix U. As a result of the test, all four legs were horizontally loaded with approximately 140 lbs. One of the legs showed a very slight plastic deformation which had a negligible effect on table usage. Overall, the test resulted in a passing measure.

7.4: Verification Summary

Table 18 presents the lists of engineering specifications we initially specified in Table 11, updated to show if the final verification prototype met the specifications set.

Table 18: Engineering Specifications and Verification Results.

Spec. #	Spec. Desc.	Requirement or Target (units)	Tolerance	Verification
1	Compact Storage	3 units/1.5x stack dimension	Min	Passed
2	Table Height	30 in.	±2 in.	Passed
3	Deployment Time	30 sec.	Max	Not Passed (33 seconds)
4	Breakdown Time	45 sec.	Max	Passed
5	Cost	$350	Max	Passed
6	Load Tipping Test	125 lb. load at edge	Min	Passed
7	Concentrated Load	200 lb.	Min	Not Passed (102 lb.)
8	Drop Test	2.4 in.	Min	Passed
9	Leg Strength	100 lb.	Max	Passed

8.0: Project Management

8.1: Overview

We have outlined the detailed overall timeline of this project and the tasks required in the Team Gantt Chart for this project (Appendix S:Gantt Chart). Roles assigned to each team member to perform the project related tasks most efficiently were as follow:

Christopher Macias – As a treasurer, Chris collected and organized receipts; he was ultimately responsible for raising necessary funding and tracking spending. He also notified team of budget constraints as necessary and ensured that parts orders are entered correctly and tracked logistics of orders and delivery.

David Yang – as a Documentarian, David supervised the documentation of the group. He communicated with Jung to make sure deadlines are kept, and when necessary he adjust formatting and aesthetic considerations of the team's work.

Ellie Kitabjian – as an outreach, Ellie worked as a point of contact of the team and ensured communication with our sponsor.

Jung Kim – as a Team Manager, Jung was responsible for knowing everyone's progress, checked in with team at least weekly to push along weekly deliverable progress.

8.2: Project-Specific Techniques

Specifically, for Spring Quarter after the critical design phase, due to the limitation of two (2) of our team members (Jung and Chris) being unable to physically be in San Luis Obispo to participate the manufacturing process of our verification prototype, manufacturing was performed by David and Ellie. Both were in San Luis Obispo and had access to the Machine shops in Cal Poly. To efficiently handle the situation, we broke up the project handling into two different parts:

Manufacturing – David and Ellie took charge of Manufacturing, assembly, testing, and prototype hand off to our sponsor. They both spent 40 hours and more on building and performing necessary testing on two (2) verification table prototype.

Documenting – Jung and Chris took charge of Final design report, updating appendices, documenting test results, expo website, ordering parts, and required administrative works. They both spent 20 hours and more to prepare documents before deadline and procuring parts necessary for manufacturing.

9.0: Conclusion and Recommendations

Through meeting with the project sponsor and a combination of user surveys, technical research, and profiling existing products, we established our scope to cover the design of a durable quick-deploy table system designed to streamline group work. Working inside our scope, we used our background research to ideate a litany of concepts to fit our problem statement. Using Pugh matrices, weighted decision matrices, and other tools, we narrowed down our ideas to three system-level concepts that we made into concept prototypes and recommended the trapezoid base table move into detailed design. Trapezoid shape table had the highest potential to meet our engineering specifications compare to the other table design candidates, including stack-ability, low deploy times, and tipping resistance. Based on design analysis, numerous verification testing, and actual manufacturing of our verification prototype, we have met almost all the requirements that we have specified and met the goals we set for this project.

Carrying over from the verification section of the report, we recommend the further improvement of the tongue and grove feature which joins the tabletops together when in deployed configuration. The design of that feature was the major reason we did not achieve the goal of supporting a concentrated load of 200 lbs. We acknowledge that our table should be able to resist such load as is mandated from the BIFMA table standard, and for future renovation of the design we shall come up with a much more durable table joining feature, not necessarily constrained to the current tongue and grove design, but possibly a completely new design through extra ideation sessions.

Other than the issue with the concentrated load, our fully built verification prototype was able to meet all the engineering specification listed in Table 11. We achieved not only the anticipated specifications but also other criteria we had not previously defined, such as wobble-free hinges and repair-friendly tabletops equipped with anchor hardware.

In conclusion, our team was glad to improve fellow Cal Poly engineering students' studying conditions through our table design and we wish our design to promote the birth of many great senior project ideas to come in Bonderson 104.

10.0: Works Cited

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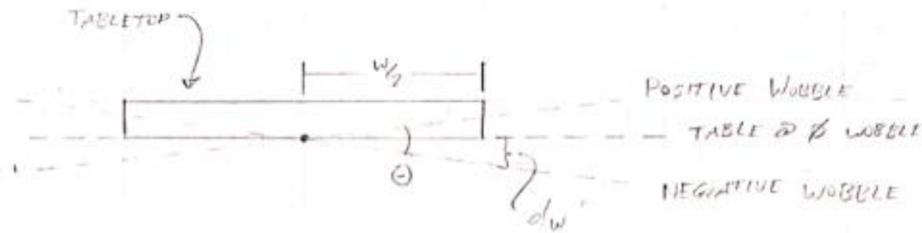
Appendix A: Existing Table Calculation

Appendix A: Existing Table Calculation

EXISTING TABLE WOBBLE



ASSUME

1) POSITIVE = NEG. WOBBLE.

TABLE WOBBLE $\equiv \Theta$ WHERE $\tan\left(\frac{\Theta}{2}\right) = \frac{d_w}{W/2}$

$$\Theta = 2\tan^{-1}\left(\frac{2d_w}{W}\right)$$

FOR BONDERSON TABLES, $W = 30$ in. AND $d_w = 0.18 \pm 10\%$

$$\Theta = 2\tan^{-1}\left(\frac{2(0.18)}{30}\right)$$

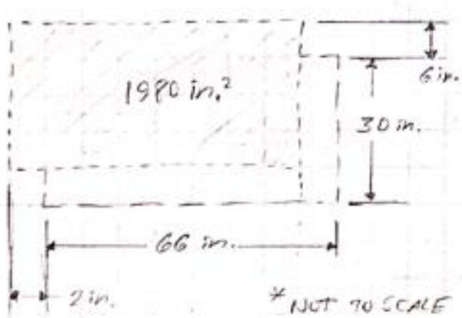
$\Theta = 1.4°$ ⟶ BONDERSON TABLE WOBBLE. NOMINAL

MAX $d_w = 0.20$ in. → $\Theta = 1.5°$

MIN $d_w = 0.16$ in. → $\Theta = 1.2°$

NOTE: UNCERTAINTY ON d_w IS DUE TO MEASUREMENT ERROR.

EXISTING TABLE STACKING



FOOTPRINT OF 1 = (66 in.)(30 in.) = 13.75 ft.²

FOOTPRINT OF 2 = (68 in.)(36 in.) = 17 ft.²

→ AREA INCREASE OF 24%

→ STACKING EFFICIENCY 76%

Appendix B: Consumer Profiles

Appendix B: Consumer Profiles

This appendix contains a collection of consumer profiles used to personify potential users and stakeholders of the design. They are generally ordered from biggest audience to smallest audience.

1. **Isaiah** is a *2nd year M.E. student in ME 234*, with an affinity for hands-on, in-person group work. He needs a space to call meetings and perform rapid prototyping to generate ideas for/with his team.

2. Design teams and project groups need a space to work more effectively as a team at their convenience because current table models lack the key combination of transportability, compact storage, surface quality, and durability for the necessary applications. Focusing on putting together a solution that meets these criteria and is cost effective, manufacturable, and reproducible will require outsourcing or adapting existing designs.

3. **Sam** is a fast-paced *upperclassman Art + Design student* leading the branding team for an engineering club. Because meeting times are short, she needs an agile workspace to support 6 people in both group and individual workspaces to foster different stages of the design process.

4. **Peter** is the M.E. department head of furniture, and really cares about the group project experience in the department. He needs an affordable, durable option that fosters group work in a multi-purpose setting.

5. **Cameron** is a 5th-year about to give his senior project presentation to company reps that may offer him a job. Stress levels are high, and competition is fierce, so he needs flexible furniture that allows him to structure his presentation space quickly in a visually appealing and impactful way, allowing him to spend less time worrying and more time presenting.

6. **Daniel** is a *wheelchair-bound engineering peer mentor* for younger students. He does not like to waste time, so he needs tables that allow him to quickly construct a 1-on-1 workspace that encourages quiet focus with his mentee.

7. **KC** is the technical director for Cal Poly Racing. Her team is not sure how the room will be configured when they walk in 5 minutes before a meeting, so they need furniture that can be hastily reconfigured into a group meeting space.

Appendix C: QFD (House of Quality)

Appendix C: QFD (House of Quality)

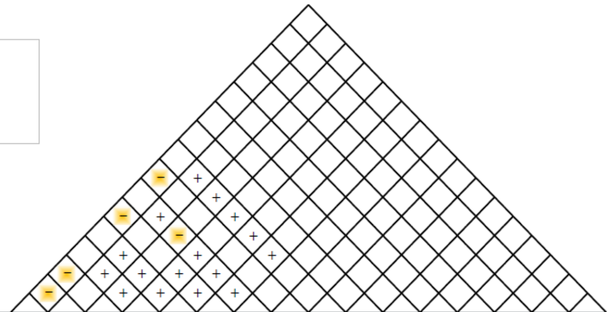
Correlations	
Positive	+
Negative	–
No Correlation	

Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

QFD House of Quality

Project: F31 Design Collaborative Space
Revision Date: 1/12/21



Row #	Weight Chart	Relative Weight	Students, group work (prototyping)	Students, group work (paper/online)	M.E. Department Furniture Head	Mobility-impaired students	Maximum Relationship	WHAT: Customer Requirements (Needs/Wants) / HOW: Engineering Specifications (Tests)	Table Height (BIFMA G1-2013 p.51)	Deployment Usage Test	Load Tipping Test (125 lbf at ed	Use Test: Prototyping	Use Test: Studying	Storage Time Test	Case Study: Long-term usage	Bill of Materials: Cost	Focus Group: Students	Stacking Efficiency (CAD Analysis)	Concentrated Load	Drop Test					Bondersen Folding Tables	Plastic 6' Table (Lifetime)	Wooden 6' Table	ATL Rolling Tables	Stanford BYO Tables	Row #
	WHO: Customers							Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	NOW: Curr. Products					
								Direction of Improvement	◇	▼	◇	▲	▲	▼	◇	◇	◇	▲												
1	||	6%	4	4	8	4	9	Compact Storage				○	○	▽	○			●							3	3	1	4	3	1
2	||||	9%	7	7	10	7	9	Durability		▽	○	○	○	▽	●				○	●					3	2	5	3	3	2
3	|	3%	1	1	9	1	9	Low-cost								●									4	4	1	3	3	3
4	||||	9%	8	8	6	8	9	Quickly deployable from storage		●		○	○		○										3	3	1	5	3	4
5	|||||	11%	10	10	7	10	9	Room re-configurablility				●	●		●										3	3	1	5	3	5
6	|	3%	2	2	6	2	9	Manufacturable In-House								●									2	2	2	1	5	6
7	|||	7%	9	5	4	7	9	Multifunctional Surface(s)				●	▽		●	○	○								3	2	3	3	4	7
8	|||	8%	7	6	7	7	9	Easy to clean/sanitize				●	●	○	●		○								3	4	3	4	3	8
9	||	6%	5	5	6	5	9	Aesthetically pleasing	▽			○	○		○		●								3	3	5	3	1	9
10	|||||	11%	10	10	8	10	9	Stable	○	○	●	●	●	○	●				○	○					3	3	5	3	3	10
11	||	5%	3	3	3	8	9	Lightweight		●		○	○	○	●	○									3	3	1	4	3	11
12	|||||	10%	9	9	10	9	9	Safety	○	●	●	●	●	○	●				●	●					3	3	4	3	3	12
13	||	5%	5	5	3	5	9	Storage options (for backpacks, et		○		●	●		●		○								2	2	2	2	2	13
14	||||	8%	7	6	7	10	9	Acommodates wide range of body types	●			●	●		●		●								3	2	2	3	3	14
15		0%																												15
16		0%																												16

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	HOW MUCH: Target Values	27.5" high	< 30 seconds	No tipping!			< 45 seconds		< $300/unit		87.5% efficiency (See Appendix H)	200lb at weakest point	survive drop of 2.4in.				
	Max Relationship	9	9	9	9	9	3	9	9	9	9	9	9				
	Technical Importance Rating	145.3	269.6	217.1	639.9	583.3	115	720.6	94.69	188.4	50.28	152.5	204.7	0	0	0	0
	Relative Weight	4%	8%	6%	19%	17%	3%	21%	3%	6%	1%	5%	6%	0%	0%	0%	0%
Curr. Products	Bondersen Folding Tables	1	3	4	2	3	5	2			3	2	3				
	Plastic 6' Table (Lifetime)	2	3	5	1	1	3	2	5		5	3	4				
	Wooden 6' Table	3	0	4	5	2	3	3	3		5	4	3				
	ATL Rolling Tables	4	1	5	4	4	4	3	1		3	5	3				
	Stanford BYO Tables	5	5	2	1	3	2	3	5		2						
	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Appendix D: Ideation Results

Appendix D: Ideation Results

This appendix contains the results of our ideation sessions. Our functional decomposition has been reproduced here for clarity.

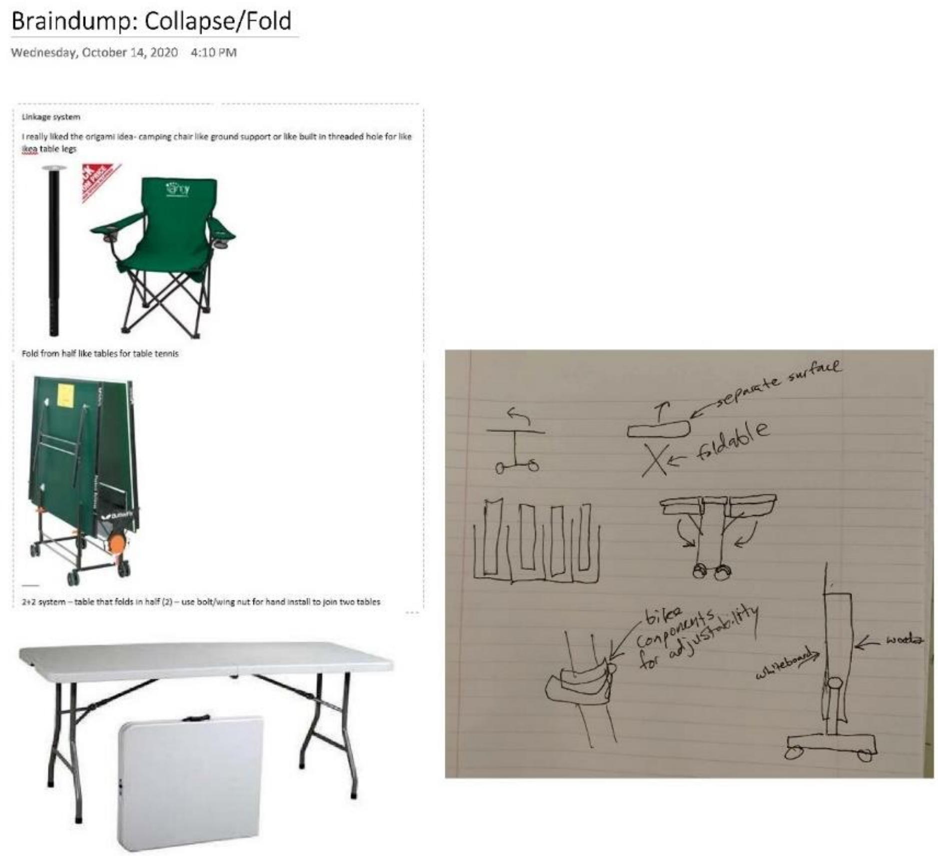


Figure D1: Braindump for the collapse/fold subfunction.

Figure D2: Brainstorm for disassemble function.

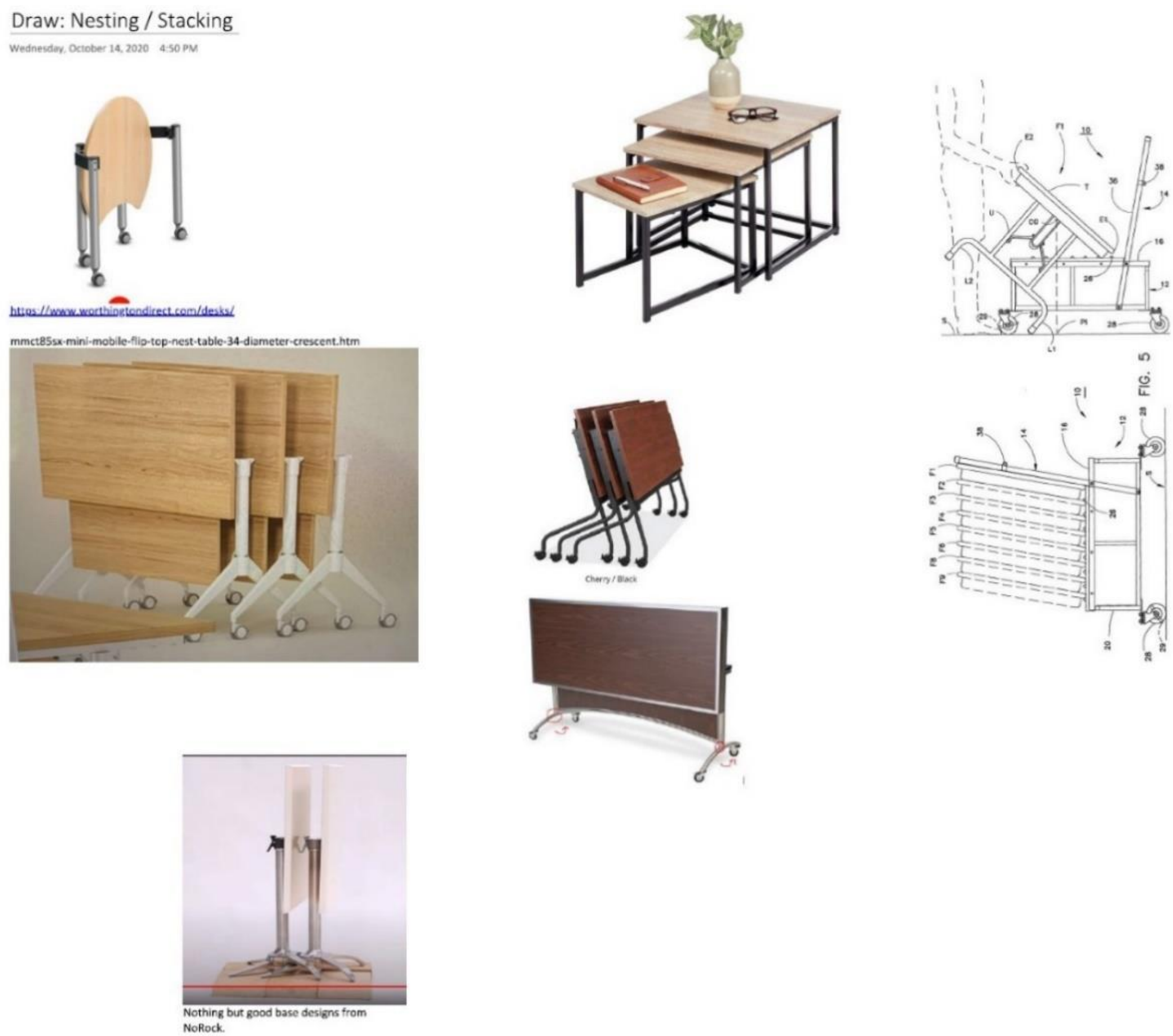


Figure D3: Draw/imaging session for nesting/stacking subfunction.

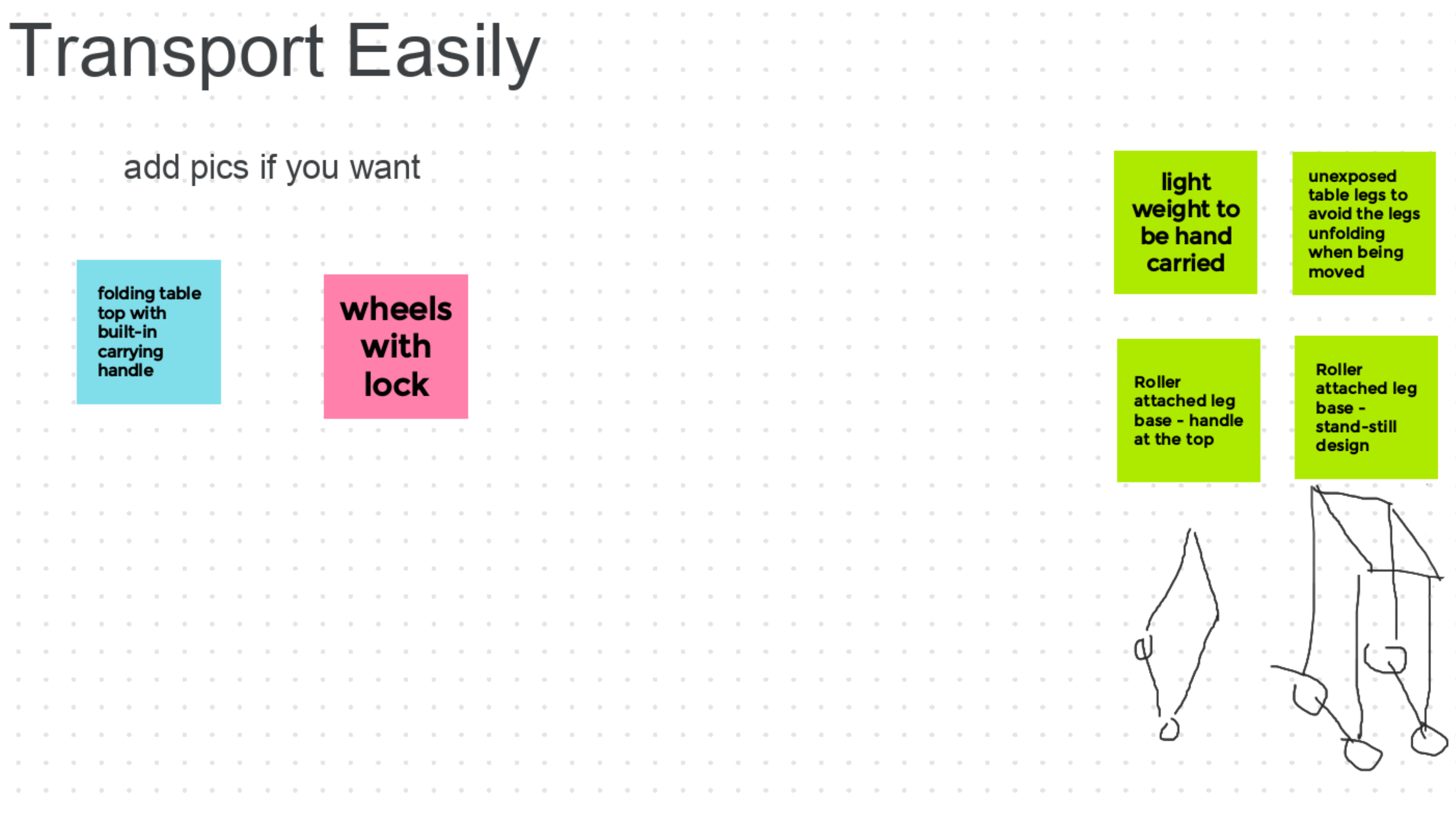


Figure D4: Brainstorm for "transport easily" subfunction.

One interesting idea that came of the "Transport Easily" brainstorm was the "roller attached leg base". Though it failed to be implemented in the final design, it presents an efficient possibility for transport with a collapsing base architecture.

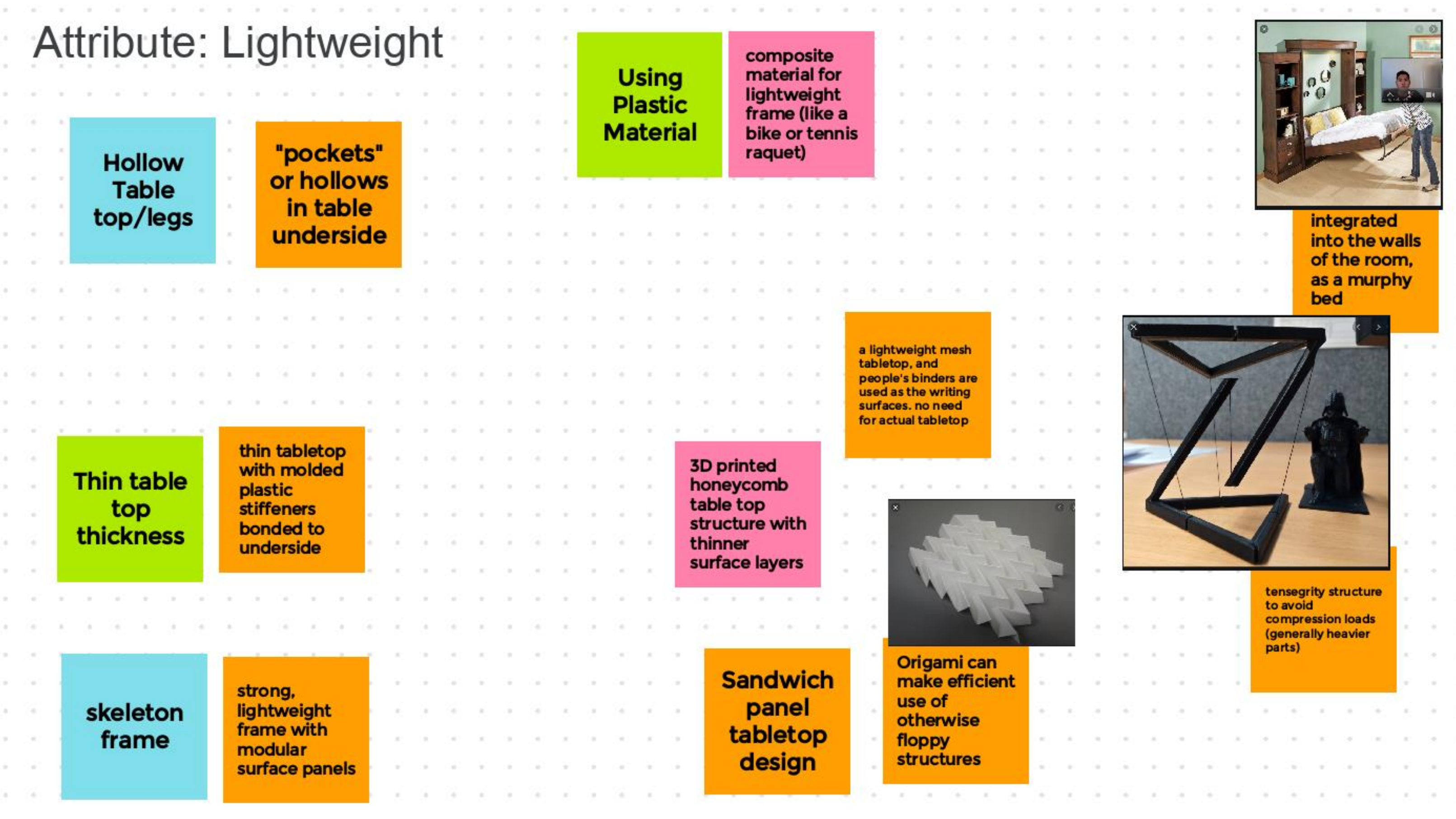


Figure D5: Brainstorm for lightweight design.

The lightweight brainstorm was especially useful in providing ideas for the final concept. Though the sandwich panel idea was considered far-fetched at first, we discovered that IKEA makes a lightweight tabletop in this style using fiberboard bonded to a honeycomb paper core. For a similar size, it is 1/3 the price and 1/3 the weight (20 vs. 60 lbs.). This weight option became an important decision point in our design process because weight and stability are positively correlated, but negatively correlated with user safety.

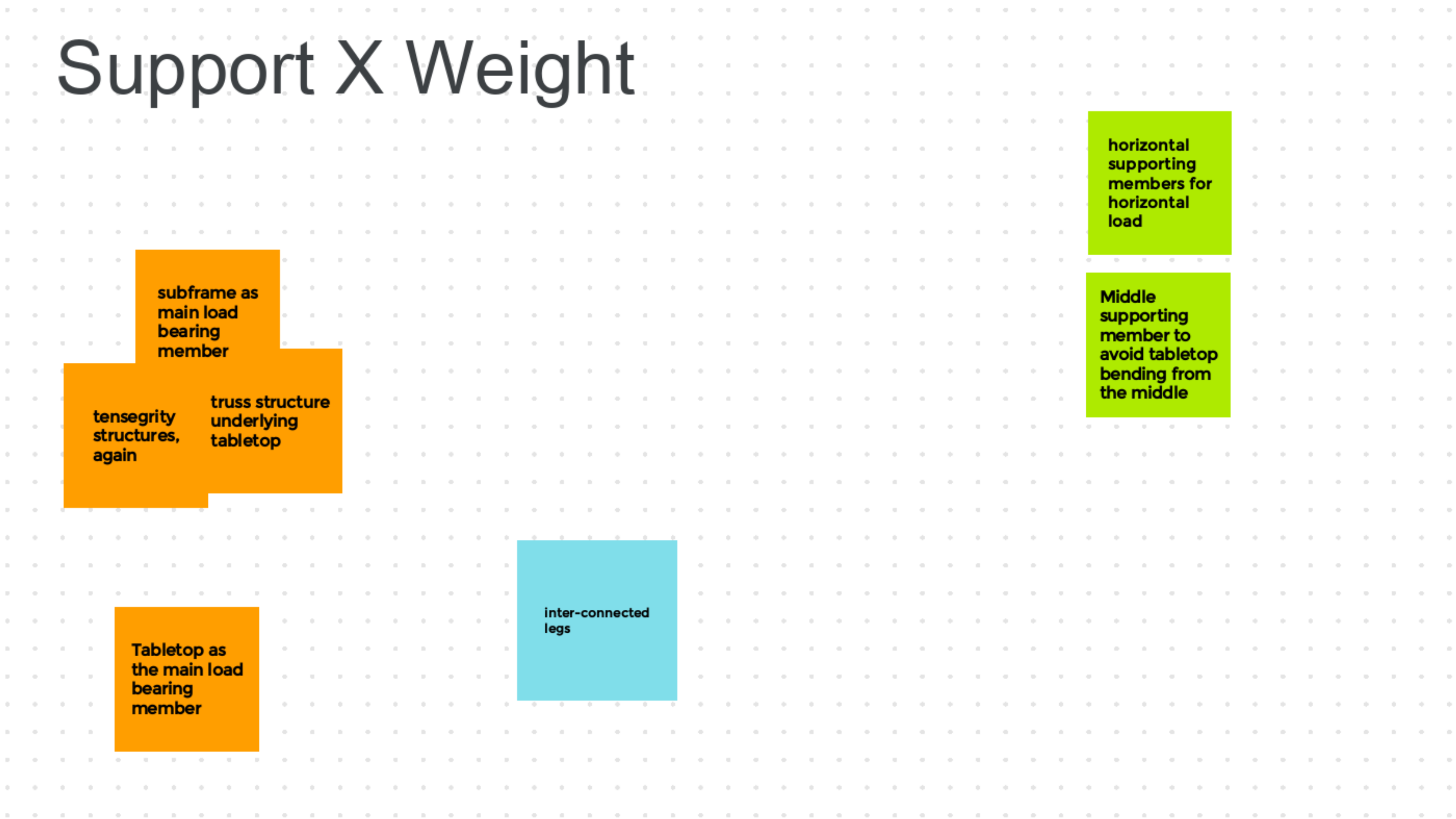


Figure D6: Brainstorm for supporting weight.

Brainstorm: Resist Tipping

Sunday, October 18, 2020 5:38 PM

Base as wide as the tabletop

Internal gyro to resist motion

Table feet with friction

Weighted base to lower CG

Tabletop attaches to chairs, where user sits

Foldable outriggers that can be extended or retracted as necessary

Suspend the thing from the ceiling

Table base locks into ground attachment points

Tabletop rests on the legs of the users

Chairs lock into the table legs when in use, effectively extending the base

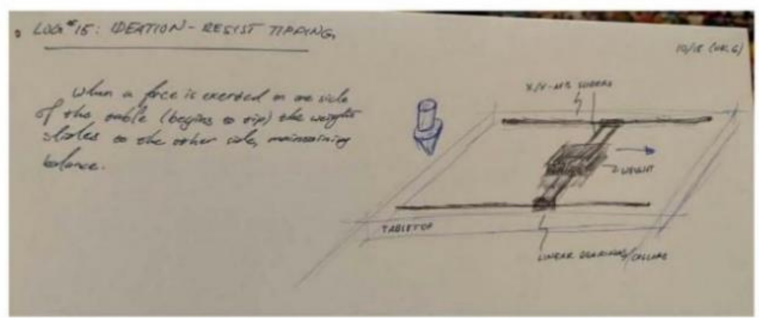


Figure D7: Brainstorm for resist tipping.

The picture in Figure D7 above represents a “crazy” idea – an active counterbalancing system. Though it is indeed undesirable for our cost constraints, the idea got our team thinking about the importance of the tabletop’s center of gravity with respect to stability.

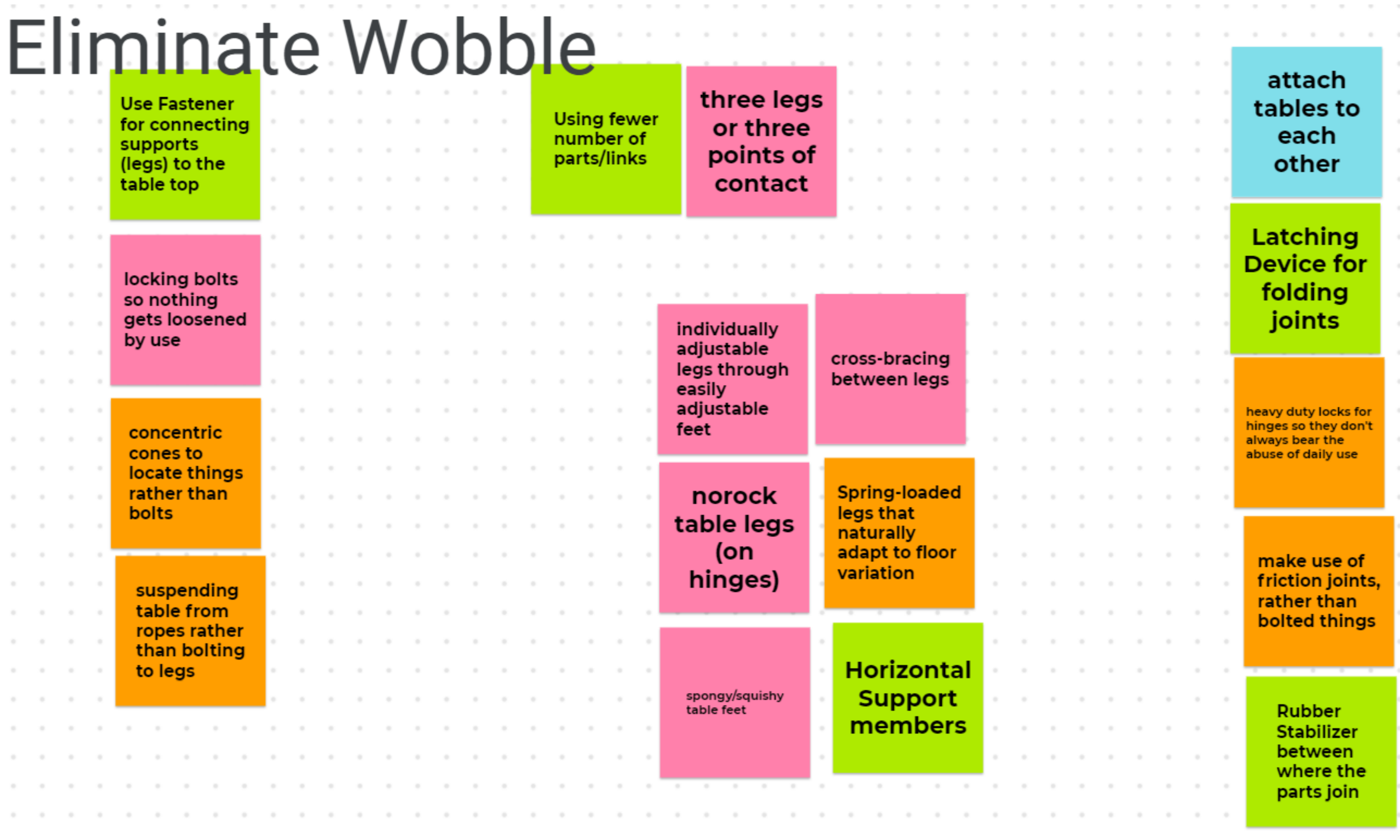


Figure D8: Brainstorm for eliminating wobble.

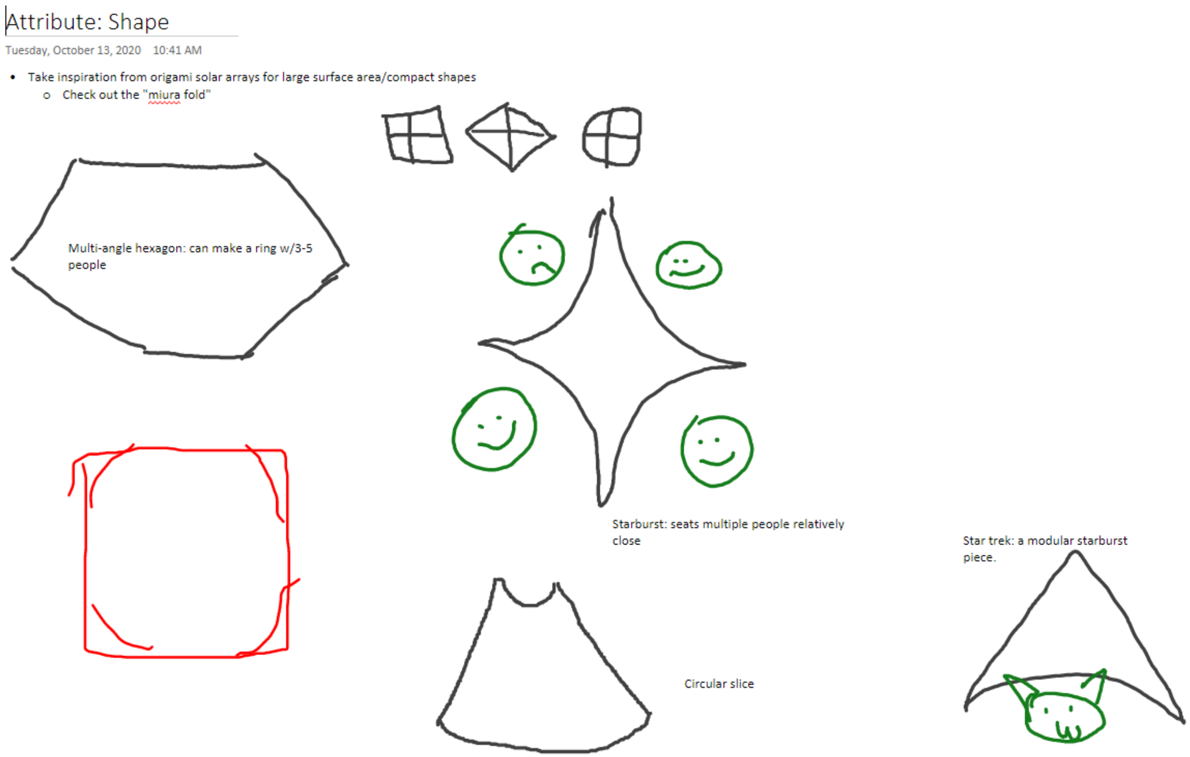


Figure D9: Draw/Image for Attribute: Shape.

The tabletop shape drawing session yielded several interesting results – the multi-angle hexagon shape was one of the unique ideas to make it into the concept prototypes. For this session, we focused on shapes at the individual and group level: individual shapes focused on placing table space around the user while retaining connection abilities for group work, while the group shapes focused on placing each member near each other. The starburst shape was another promising idea that could be split at the individual level yet work well in a group configuration.

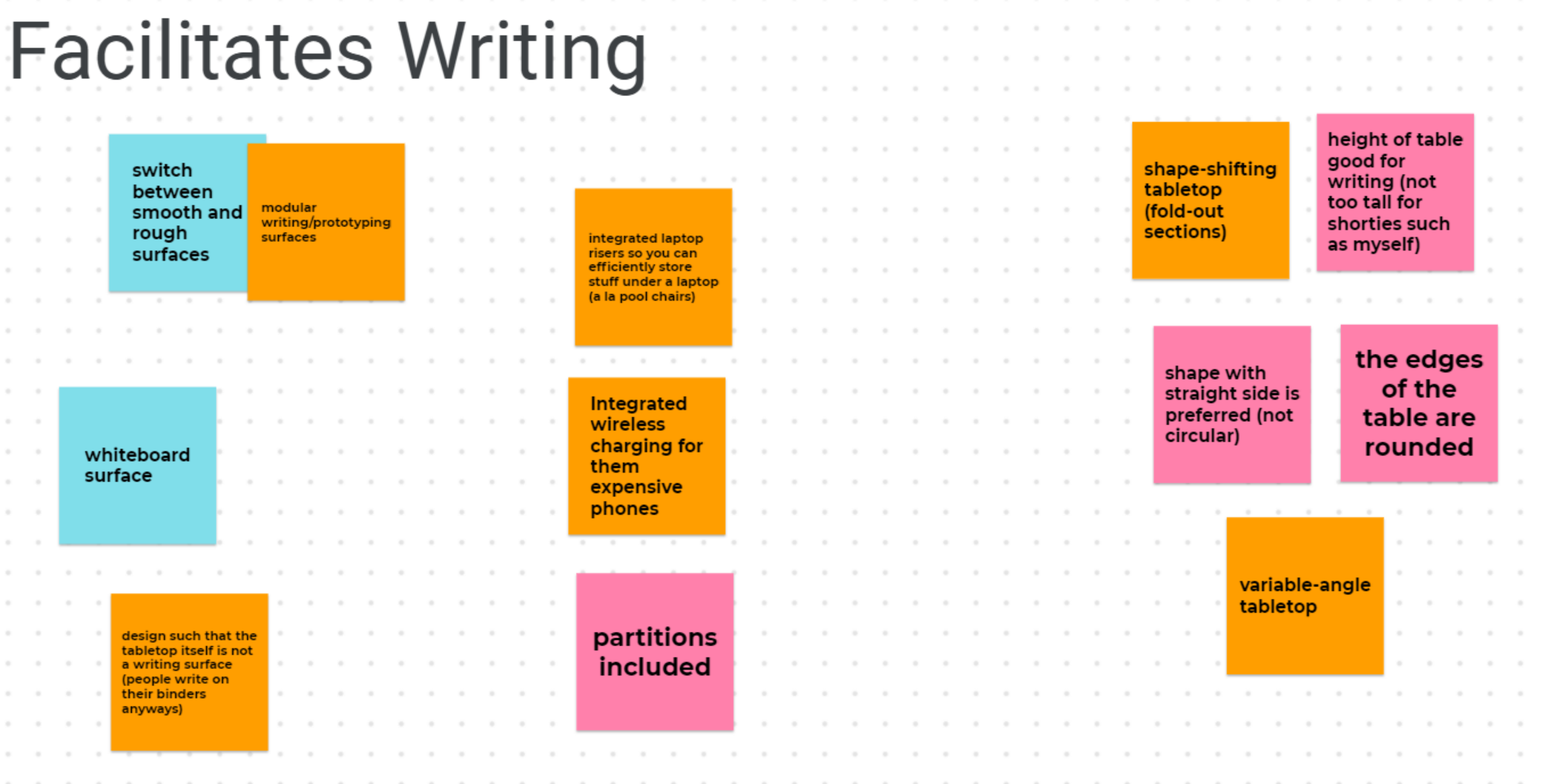


Figure D10: Brainstorm for facilitates writing.

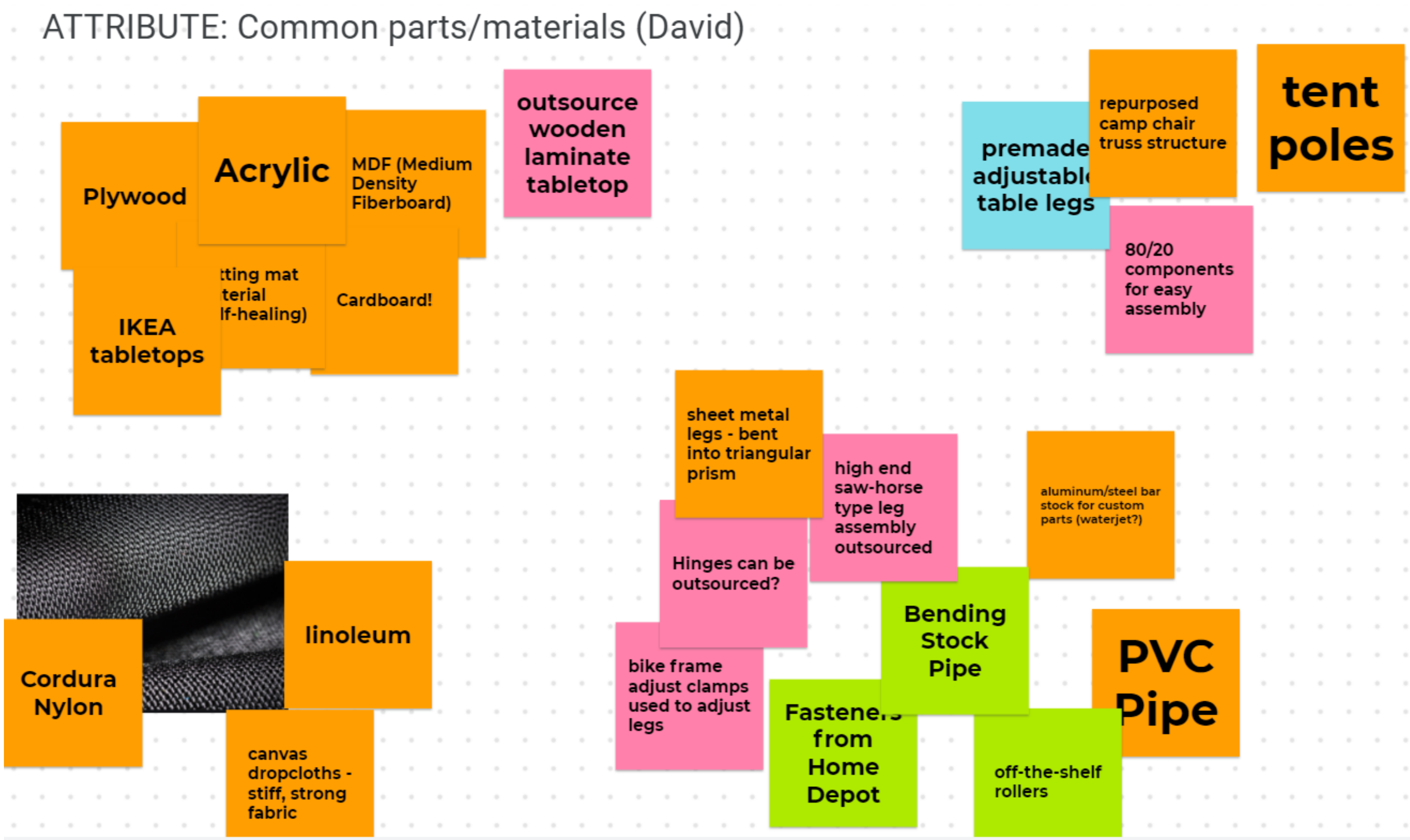


Figure D11: Brainstorm for common parts/materials.

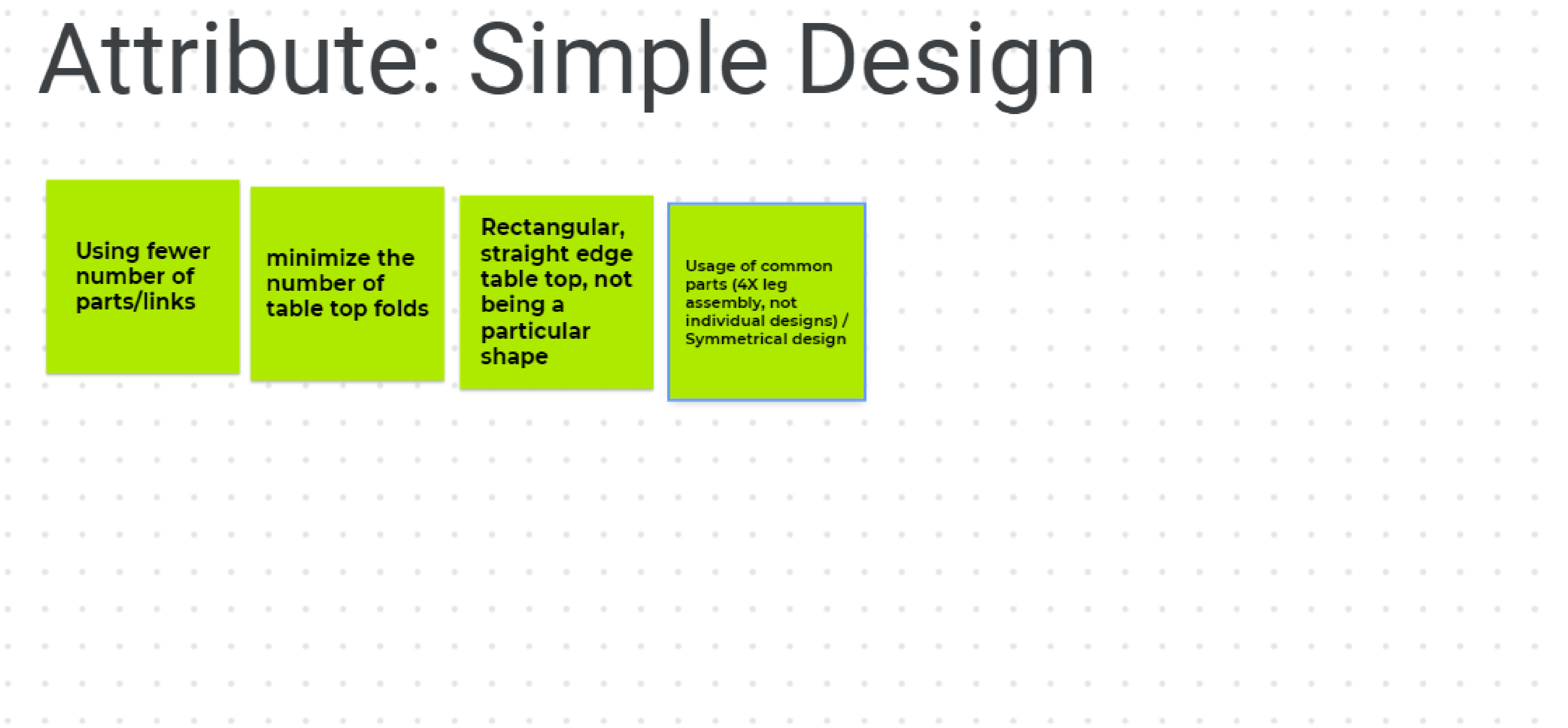
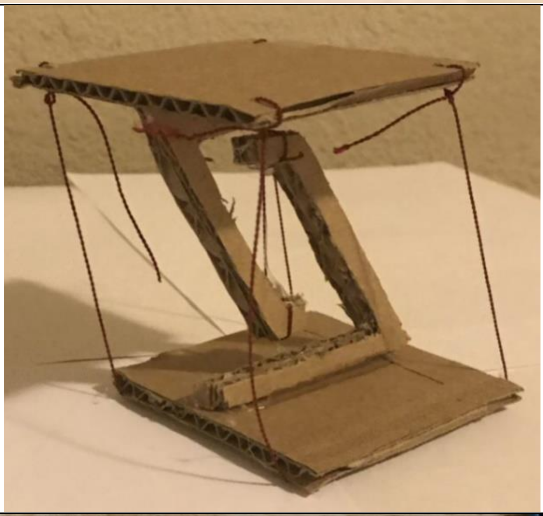
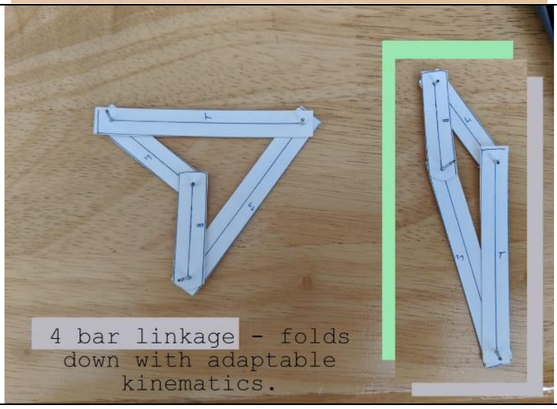


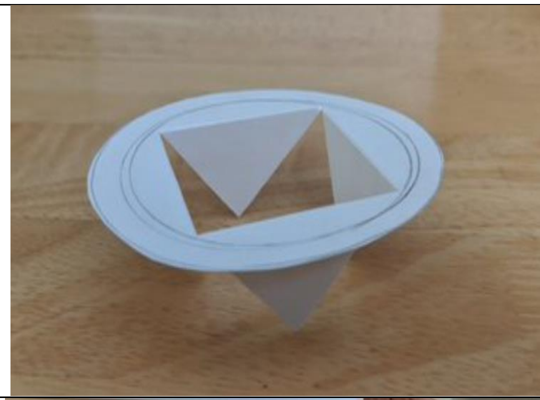
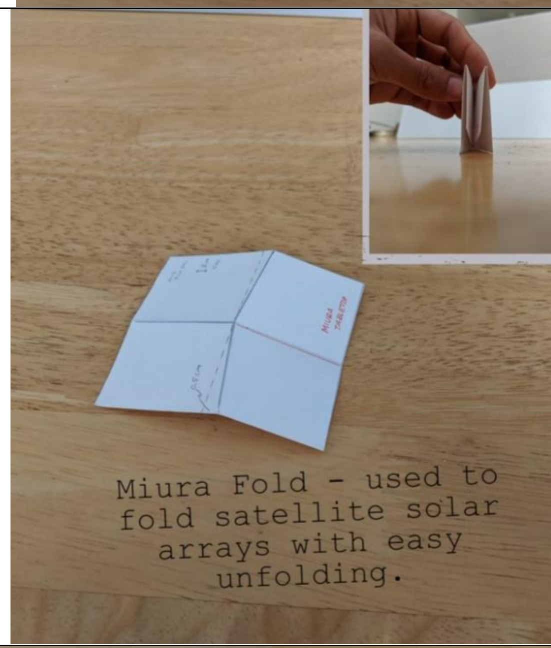
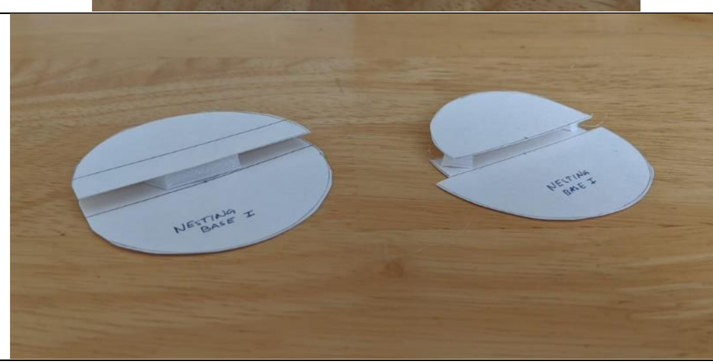
Figure D12: Brainstorm for simple design.

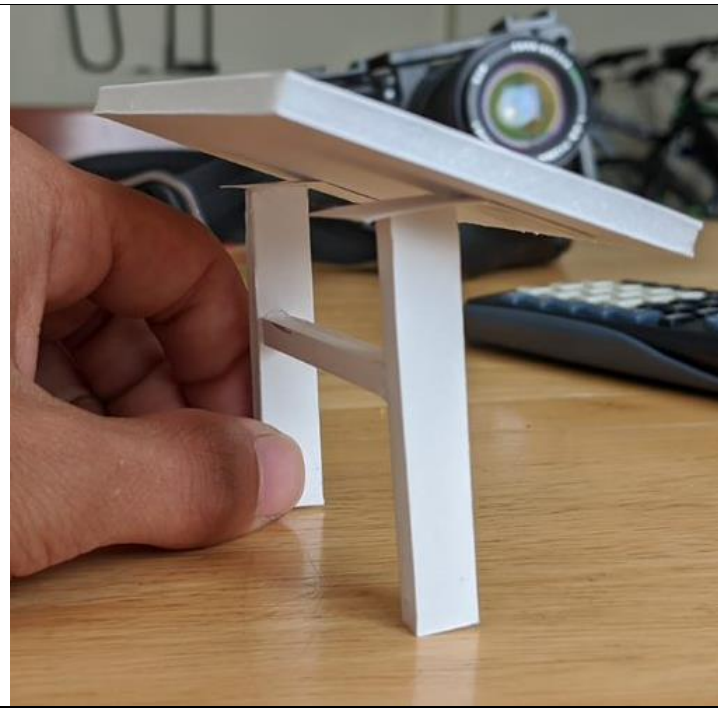
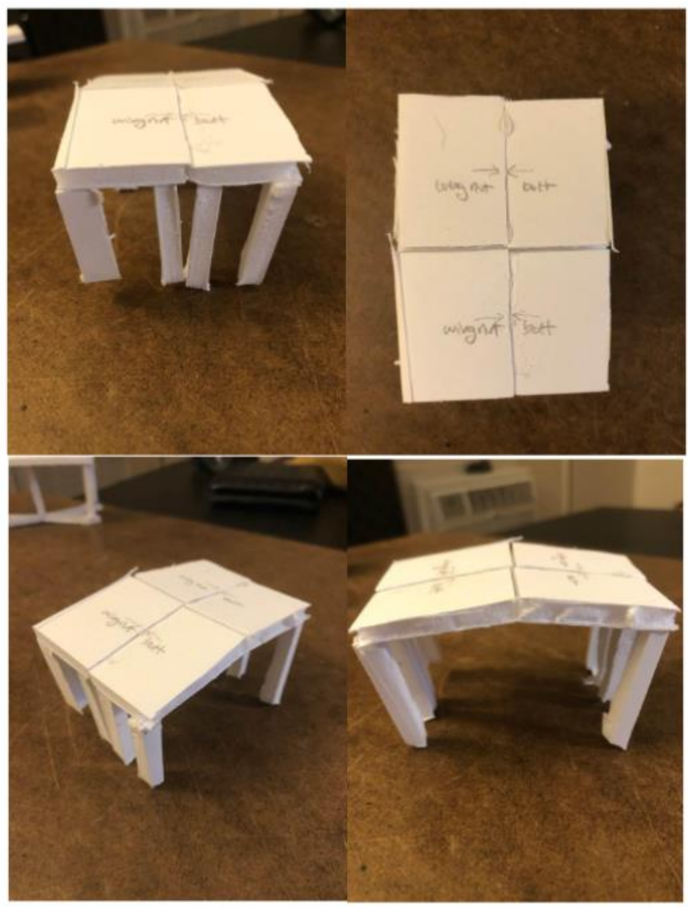
Table D1: F31 Functional Prototypes

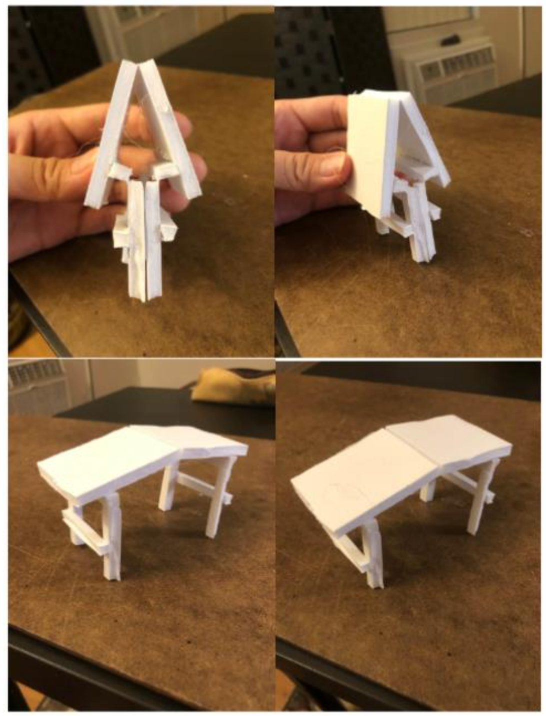
1	Function: Promote Collaboration Sub-function: Attribute: Shape / Accommodate multiple users Special shaped tabletop to accommodate different number of users to collaborate using multiple tabletop layouts.	
2	Function: Promote Collaboration Sub-function: Provide Personal Workspace Cubby attached in the table to provide storage space.	
3	Function: Promote Collaboration Sub-function: Accommodate multiple users Bag hangers under the table tops to provide more working space and accommodate more users.	

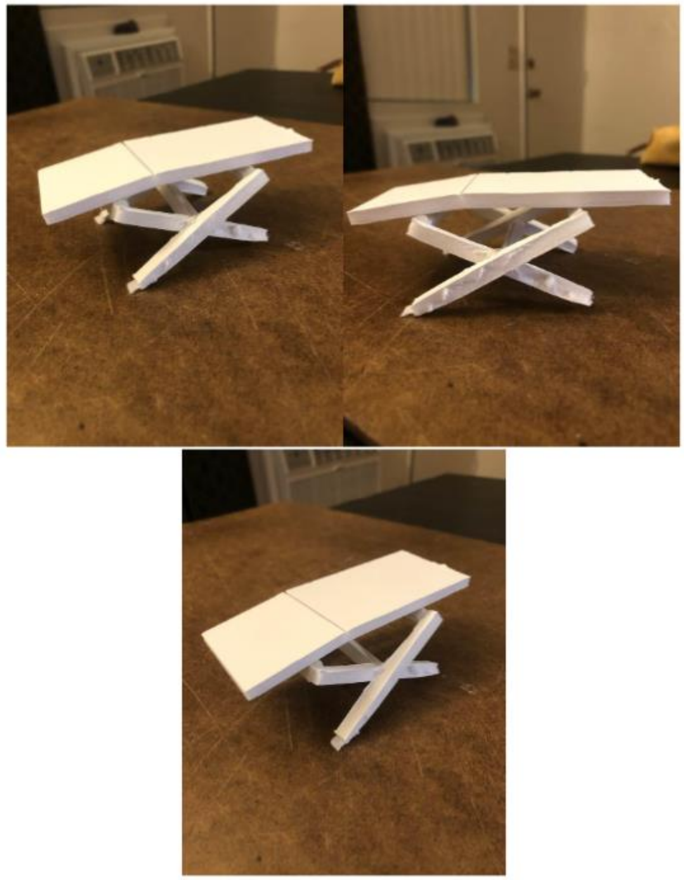
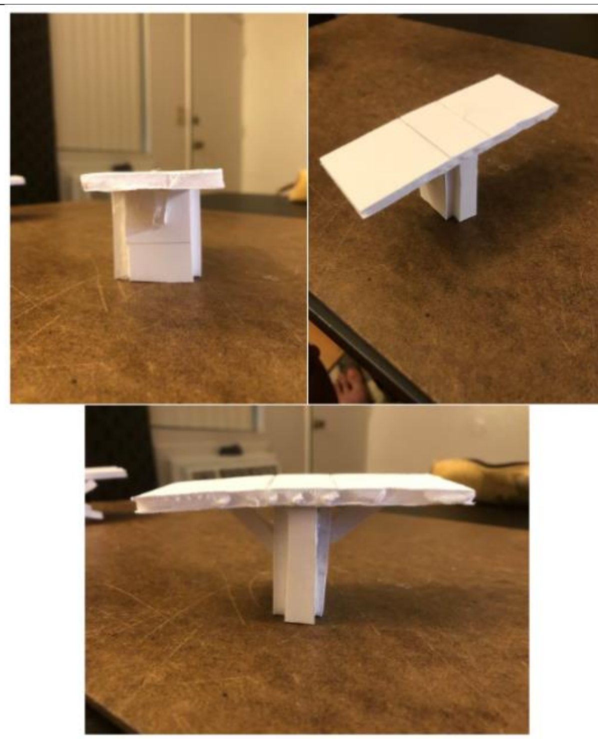
4	Function: Maximize stability Sub-function: Resist tipping / Eliminate wobble Height adjustable legs to increase tipping stability / adjustable mechanism locking function to eliminate wobble.	
5	Function: Maximize Stability Sub-function: Resist tipping / Support "X" weight X-cross member to vertically stabilize table from tipping. X-cross member being a third leg; allows table to support more weight	
6	Function: Maximize Stability Sub-function: Resist tipping / Support "X" weight Cross member to stabilize table horizontally and vertically to prevent tipping and wobbling. Also increases weight capacity.	

7	Function: Maximize Stability Sub-function: Resist tipping triangular shaped members to support single leg in the middle, provide more ground contact thus more stabilized from tipping.	
8	Function: Maximize Stability Sub-function: Resist tipping Tensegrity structure is stabilized from tipping-over but is inevitable from wobbling.	
9	Function: Store Compactly Sub-function: Collapse/fold 4 bar linkage tabletop boundary to be linearly folded.	

10	Function: Store Compactly Sub-function: Collapse/fold Circular table with the legs being the middle portion of the table assembly	
11	Function: Store Compactly Sub-function: Collapse/fold Miura fold – detachable table top folded up compactly like origami (paper folding)	
12	Function: Store Compactly Sub-function: Nesting/Stacking leveled circular tables to nest on top of each other for storage	

13	Function: Store Compactly Sub-function: Collapse/fold Tabletop to be folded down for the assembly to be stored in a plane manner.	
14	Function: Store Compactly Sub-function: Disassemble Two bi-folding tables to be attached with hardware when used and disassembled to be stored away	

15	Function: Stow Quickly Sub-function: Quick folding / transport easily Wheeled bottoms standing still design / simultaneous table + leg folding	
16	Function: Stow Quickly Sub-function: Quick folding Z-axis folding legs with diagonal folding tabletop	

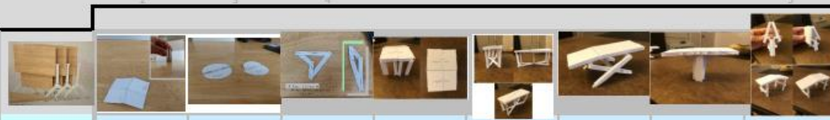
17	Function: Stow Quickly Sub-function: Quick folding / transport easily Y-axis folding legs with middle folding latching table	
18	Function: Stow Quickly Sub-function: Quick folding Middle winged collapsing table	

Appendix E: Pugh Matrices

Appendix E: Pugh Matrices

Pugh Matrix - A Decision Matrix

Problem/Situation: Store Compactly



#	Criteria	Baseline: Bondersen Tables	Removable, Miura fold tabletop	Static table, nesting bases	4-bar linkage (folding tabletop)	Two folding tables joined w/fasteners	Z-axis folding legs w/diagonal fold table	Y-axis folding legs w/middle hinge	Trifold Winged Table	Middle-fold, hinged table	Totals	Rank
1	Minimizes storage footprint	0	+	-	0	+	0	+	-	+		
2	Short Deployment	0	-	+	0	-	-	-	-	0		
3	Short Breakdown	0	-	+	0	-	+	-	0	+		
4	Cost	0	-	0	-	-	-	-	0	0		
5	Durability (likelihood of breaking)	0	-	+	+	0	0	-	0	0		
6	Safety - Minimizes pinch points	0	-	+	-	-	-	-	-	0		
7	Inherent Wobble	0	+	+	+	0	+	0	0	+		
8	Manufacturability	0	0	+	0	0	-	0	-	0		
9	Usability	0	-	-	0	-	-	-	-	0		
		Totals	-4	4	0	-4	-3	-5	-5	3		
		Rank	5	1	3	5	4	6	6	2		

Comments/Conclusion:
The static nesting table design is the clear winner. It has the only advantage in several categories: short deployment time, safety, and manufacturability. Its only downsides are usability (less overall opportunity to add features) and a larger inherent footprint. However, both of these downsides can be mitigated through careful design. The middle fold table is another strong option: similar to the standard table, but with the potential for an even smaller footprint and less inherent wobble due to the size of the hinging areas.

Figure E1: Pugh Matrix, Stow Compactly

Pugh Matrix - A Decision Matrix

Problem/Situation: Stow Quickly

#	Criteria	Baseline: Bondersen Tables	Alternatives: Removable Miura Fold Tabletop	Static Table Nesting Bases	Y-axis Folding Legs with Middle Hinge (Wheeled Bottom)	Trifold Winged Table	Middle Fold Hinged Table (Wheeled Bottom)	Two Folding Tables Joined with Fasteners	Z-axis Folding Legs with Diagonal Folding Table	Totals	Rank
1	Transport quickly	0	-	-	0	0	0	-	-	-3	3
2	Attribute: light weight	0	0	0	-	-	0	-	0	-3	3
3	Collapse quickly	0	0	0	0	0	0	-	0	-1	1
4	# of people collapsing / folding (Baseline:1)	0	0	0	0	0	0	-	0	-1	1
5	# of people transporting (Baseline:1)	0	-	-	0	0	0	-	-	-4	5
6	Static configuration (Can the table stay standing up to mobilize?)	0	-	-	-	0	0	-	-	-5	6
7		0									
8		0									
9		0									
		Totals	-2	-2	-1	-1	0	-6	-3		
		Rank	4	4	2	2	1	7	6		

Comments/Conclusion:
Proposed designs heavly rely on the compact storage function. Middle Fold Hinged Table with Wheeled Bottom design shows the same functional of being stow quickly as the existing Bondersen Tables. However, all the other designs are shown to be deficient in stow quickly function compare to the Bondersen Tables.

Figure E2: Pugh Matrix, Stow Quickly

Pugh Matrix - A Decision Matrix

Problem/Situation: Maximize Stability

Criteria	Baseline: Two Leg Pairs	Alternatives 1: Tensegrity	2: Cylindrical Base	3: Cross-Bracing	4: Middle Support	5: Horizontal Support	Totals	Rank
1 Supports Weight	0	+	0	+	+	+	2	3
2 Prevents Wobbling	0	−	+	+	+	0	3	2
3 Prevents Tipping	0	+	+	+	+	0	4	1
4 Manufacturability	0	−	0	−	−	−	-4	9
5 Compactibility	0	+	0	−	−	−	0	8
6 Leg Strength	0	0	+	+	0	+	1	4
7	0						0	
8	0						0	
9	0						0	
	Totals	1	3	2	1	-1		
	Rank	3	1	2	3	5		

Figure E3: Pugh Matrix, Maximize Stability

Pugh Matrix - A Decision Matrix

Problem/Situation:

Criteria	Baseline	Alternatives 1: Triangle (single user)	2: Square	3: Circle	4: Hexagon (single user)	5: Starburst	Totals	Rank
1 ample room for personal workspace	0	−	0	−	+	+	0	6
2 improved communication and collaboration	0	0	+	+	+	+	4	1
3 common (easy to manufacture/purchase)	0	−	0	0	−	−	-3	9
4 straight edges for individuals to work at	0	0	0	−	+	−	-1	7
5 reconfigurable	0	+	+	−	+	−	1	2
6 reproducability (number needed)	0	−	0	0	−	0	-2	8
7	0						0	
8	0						0	
9	0						0	
	Totals	-2	2	-2	2	-1		
	Rank	4	1	4	2	3		

Figure E4: Pugh Matrix, Shape

Appendix F: Morphological Matrix

Appendix F: Morphological Matrix

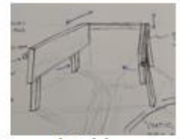
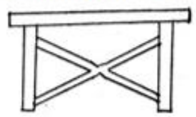
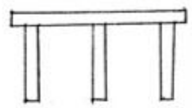
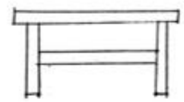
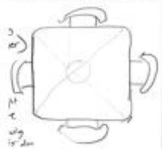
Function	Importance	Possible Solutions					
Store Compactly	9	 Nesting Bases	 Middle Fold Hinge	 Internal Fold	 4-bar linkage fliptop	 Single-axis flip top (Baseline)	Removable Tabletop
Stow Quickly	9	 Middle Fold Hinge	 Y-axis Folding legs with middle hinge	 Single-Axis flip top (Baseline)	 Trifold winged		
Maximize Stability	9	 Cylindrical Base	 Cross-Bracing	 Middle Support	 Horizontal Support	 Tensegrity	
Shape	5	 Square	 Hexagon (single user)	 Rectangle (Baseline)	 Circle	 Starburst	 Triangle (single user)

Figure F1: We used our morphological matrix to develop system concepts for the weighted decision matrix.

Appendix G: Weighted Decision Matrix

Appendix G: Weighted Decision Matrix

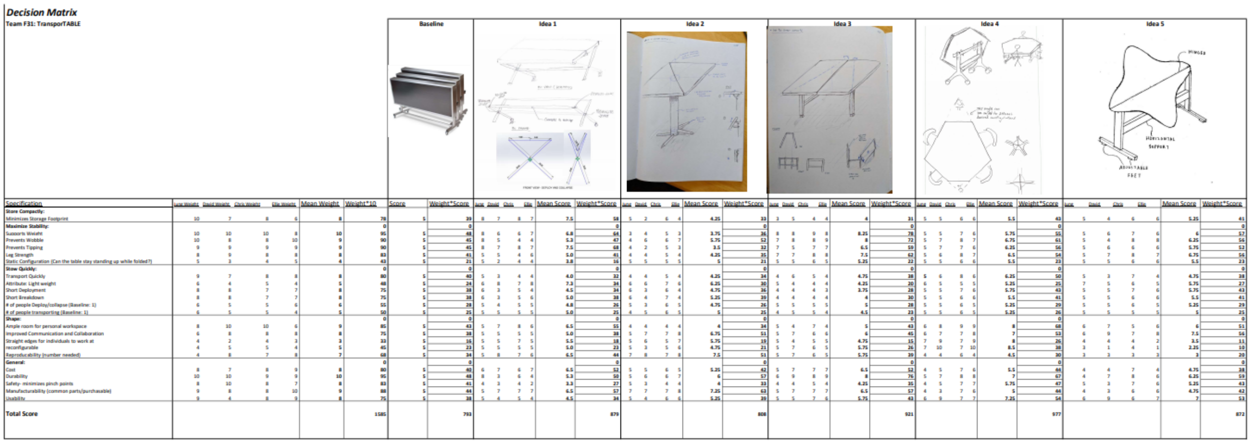


Figure G1: Our weighted decision matrix includes 5 design ideas from the morphological matrix. The baseline category uses the current tables as a datum. The following figures will detail each of the columns.

Decision Matrix

Team F31: TransporTABLE

Specification	Jung Weight	David Weight	Chris Weight	Ellie Weight	Mean Weight	Weight*10
Store Compactly:						
Minimizes Storage Footprint	10	7	8	6	**8**	**78**
Maximize Stability:						**0**
Supports Weight	10	10	10	8	**10**	**95**
Prevents Wobble	10	8	8	10	**9**	**90**
Prevents Tipping	9	9	9	9	**9**	**90**
Leg Strength	8	9	8	8	**8**	**83**
Static Configuration (Can the table stay standing up while folded?)	5	3	4	5	**4**	**43**
Stow Quickly:						**0**
Transport Quickly	9	7	8	8	**8**	**80**
Attribute: Light weight	6	4	5	4	**5**	**48**
Short Deployment	8	8	7	7	**8**	**75**
Short Breakdown	8	8	7	7	**8**	**75**
# of people Deploy/collapse (Baseline: 1)	6	5	5	6	**6**	**55**
# of people transporting (Baseline: 1)	6	5	5	4	**5**	**50**
Shape:						**0**
Ample room for personal workspace	8	10	10	6	**9**	**85**
Improved Communication and Collaboration	6	8	8	8	**8**	**75**
Straight edges for individuals to work at	4	2	4	3	**3**	**33**
reconfigurable	4	5	5	4	**5**	**45**
Reproducability (number needed)	4	8	7	8	**7**	**68**
General:						**0**
Cost	8	7	8	9	**8**	**80**
Durability	10	10	9	9	**10**	**95**
Safety- minimizes pinch points	8	10	8	7	**8**	**83**
Manufacturability (common parts/purchasable)	9	8	8	10	**9**	**88**
Usability	9	4	8	9	**8**	**75**
Total Score						**1585**

Figure G2: The weights of the decision matrix. Each criterion was weighted by each member, and then our weights were averaged into a final weight for the criteria. Stability, durability, and safety criteria are weighted highly.

Appendix G: Weighted Decision Matrix

Decision Matrix

Team F31: TransporTABLE

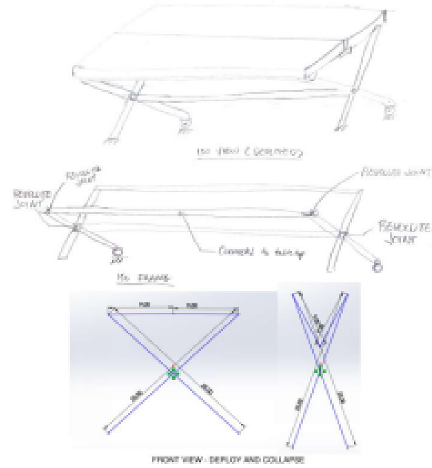
	Baseline		Idea 1					
								
Specification	Score	Weight*Score	Jung	David	Chris	Ellie	Mean Score	Weight*Score
Store Compactly:								
Minimizes Storage Footprint	5	39	8	7	8	7	7.5	58
Maximize Stability:		0						0
Supports Weight	5	48	8	6	6	7	6.8	64
Prevents Wobble	5	45	8	5	4	4	5.3	47
Prevents Tipping	5	45	8	7	8	7	7.5	68
Leg Strength	5	41	5	5	4	6	5.0	41
Static Configuration (Can the table stay standing up while folded?)	5	21	5	2	4	4	3.8	16
Stow Quickly:		0						0
Transport Quickly	5	40	5	3	4	4	4.0	32
Attribute: Light weight	5	24	6	8	7	8	7.3	34
Short Deployment	5	38	6	3	5	4	4.5	34
Short Breakdown	5	38	6	3	5	6	5.0	38
# of people Deploy/collapse (Baseline: 1)	5	28	5	4	5	5	4.8	26
# of people transporting (Baseline: 1)	5	25	5	5	5	5	5.0	25
Shape:		0						0
Ample room for personal workspace	5	43	5	7	8	6	6.5	55
Improved Communication and Collaboration	5	38	5	5	5	5	5.0	38
Straight edges for individuals to work at	5	16	5	5	7	5	5.5	18
reconfigurable	5	23	5	5	5	5	5.0	23
Reproducability (number needed)	5	34	5	8	7	6	6.5	44
General:		0						0
Cost	5	40	6	7	6	7	6.5	52
Durability	5	48	8	3	6	4	5.3	50
Safety- minimizes pinch points	5	41	4	3	4	2	3.3	27
Manufacturability (common parts/purchasable)	5	44	5	7	7	7	6.5	57
Usability	5	38	5	4	5	4	4.5	34
Total Score		793						879

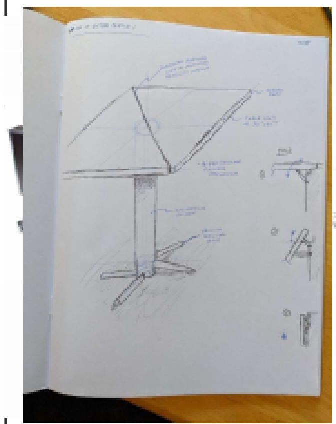
Figure G3: The current tables in Bonderson, and the first concept prototype: the folding-X table. The current table scores the lowest out of all the ideas analyzed. The folding X ranks #3 in the new ideas considered; it scores well generally but is not standout in any category.

Appendix G: Weighted Decision Matrix

Decision Matrix

Team F31: TransporTABLE

Idea 2



Idea 3

Specification	Idea 2						Idea 3					
	Jung	David	Chris	Ellie	Mean Score	Weight*Score	Jung	David	Chris	Ellie	Mean Score	Weight*Score
Store Compactly:												
Minimizes Storage Footprint	5	2	6	4	4.25	33	3	5	4	4	4	31
Maximize Stability:						0						0
Supports Weight	3	4	5	3	3.75	36	8	8	9	8	8.25	78
Prevents Wobble	4	6	6	7	5.75	52	7	8	8	9	8	72
Prevents Tipping	4	2	5	3	3.5	32	7	5	7	7	6.5	59
Leg Strength	4	4	5	4	4.25	35	7	7	8	8	7.5	62
Static Configuration (Can the table stay standing up while folded?)	5	5	5	5	5	21	5	5	6	5	5.25	22
Stow Quickly:						0						0
Transport Quickly	4	4	5	4	4.25	34	4	6	5	4	4.75	38
Attribute: Light weight	6	6	7	6	6.25	30	5	4	4	4	4.25	20
Short Deployment	6	3	6	4	4.75	36	4	4	4	3	3.75	28
Short Breakdown	6	4	7	4	5.25	39	4	4	4	4	4	30
# of people Deploy/collapse (Baseline: 1)	5	3	6	5	4.75	26	5	5	5	5	5	28
# of people transporting (Baseline: 1)	4	5	6	5	5	25	4	5	5	4	4.5	23
Shape:						0						0
Ample room for personal workspace	4	4	4	4	4	34	5	4	7	4	5	43
Improved Communication and Collaboration	5	7	7	8	6.75	51	5	7	6	6	6	45
Straight edges for individuals to work at	5	6	5	7	5.75	19	5	4	5	5	4.75	15
reconfigurable	5	3	5	6	4.75	21	5	7	6	5	5.75	26
Reproducability (number needed)	7	8	7	8	7.5	51	5	7	6	5	5.75	39
General:						0						0
Cost	5	5	6	5	5.25	42	5	7	7	7	6.5	52
Durability	5	6	6	7	6	57	6	9	8	9	8	76
Safety- minimizes pinch points	5	3	4	4	4	33	4	4	5	4	4.25	35
Manufacturability (common parts/purchasable)	7	7	7	8	7.25	63	5	7	7	7	6.5	57
Usability	5	4	6	6	5.25	39	5	5	7	6	5.75	43
Total Score						808						921

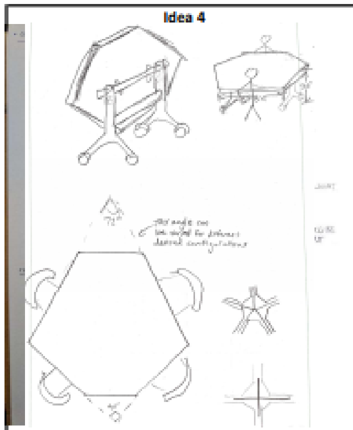
Figure G4: The center column-based design and the trapezoid base table. The center column design scores low in the stability and safety categories. The trapezoid table scores well in each category and is one of two that moved into full prototype preceding PDR.

Appendix G: Weighted Decision Matrix

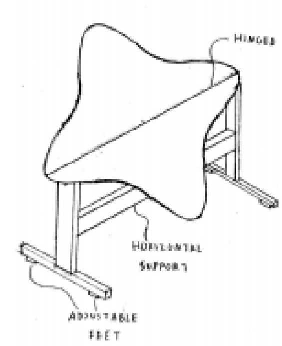
Decision Matrix

Team F31: TransporTABLE

Idea 4



Idea 5



	Idea 4						Idea 5					
Specification	June	David	Chris	Ellie	Mean Score	Weight*Score	June	David	Chris	Ellie	Mean Score	Weight*Score
Store Compactly:												
Minimizes Storage Footprint	5	5	6	6	5.5	43	5	4	6	6	5.25	41
Maximize Stability:						0						0
Supports Weight	5	5	7	6	5.75	55	5	6	7	6	6	57
Prevents Wobble	5	7	8	7	6.75	61	5	4	8	8	6.25	56
Prevents Tipping	5	7	7	6	6.25	56	5	6	6	6	5.75	52
Leg Strength	5	6	8	7	6.5	54	5	7	8	7	6.75	56
Static Configuration (Can the table stay standing up while folded?)	5	5	6	6	5.5	23	5	5	6	6	5.5	23
Stow Quickly:						0						0
Transport Quickly	5	6	8	6	6.25	50	5	3	7	4	4.75	38
Attribute: Light weight	6	5	5	5	5.25	25	7	5	6	5	5.75	27
Short Deployment	5	5	7	6	5.75	43	5	5	7	6	5.75	43
Short Breakdown	5	5	6	6	5.5	41	5	5	6	6	5.5	41
# of people Deploy/collapse (Baseline: 1)	5	5	6	5	5.25	29	5	5	6	5	5.25	29
# of people transporting (Baseline: 1)	5	5	6	5	5.25	26	5	5	5	5	5	25
Shape:						0						0
Ample room for personal workspace	6	8	9	9	8	68	6	7	5	6	6	51
Improved Communication and Collaboration	6	7	7	8	7	53	6	9	7	8	7.5	56
Straight edges for individuals to work at	7	9	7	9	8	26	4	4	4	2	3.5	11
reconfigurable	7	10	7	10	8.5	38	3	1	4	1	2.25	10
Reproducability (number needed)	4	4	6	4	4.5	30	3	3	3	3	3	20
General:						0						0
Cost	4	5	7	6	5.5	44	4	4	7	4	4.75	38
Durability	5	7	8	8	7	67	4	7	8	6	6.25	59
Safety- minimizes pinch points	4	5	7	7	5.75	47	5	3	7	6	5.25	43
Manufacturability (common parts/purchasable)	4	3	7	6	5	44	4	3	6	6	4.75	42
Usability	6	9	7	7	7.25	54	6	9	6	7	7	53
Total Score						977						872

Figure G5: The folding hex table and split starburst table. The hex table scored the highest of the compared ideas and moved on to concept prototyping along with the trapezoid table. The split starburst table scored well in stability but3fell short in usability.

Appendix H: Concept Prototype Analysis

Appendix H: Concept Prototype Analysis

Stacking Efficiency

To determine the stacking efficiency, we first defined the “stacking dimension” – a footprint dimension that increases when multiple tables are stacked together. Provided are the sample calculation based on the trapezoid base concept. Figure H-1 below defines the relevant dimensions. Our largest takeaway is that the tabletop thickness and frame tube thickness must be reduced as much as possible to increase stacking efficiency.

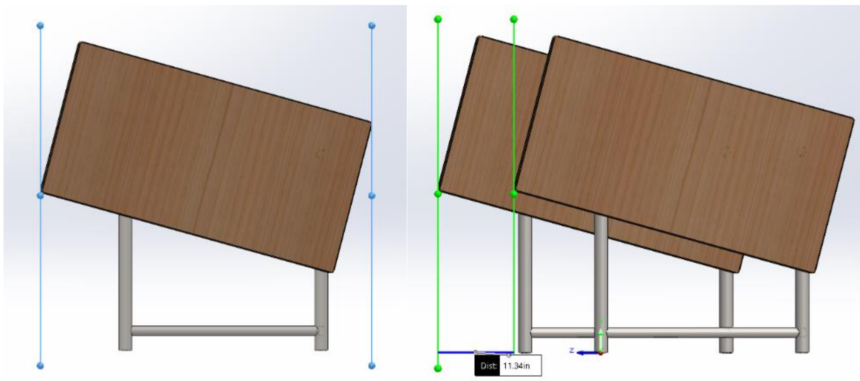


Figure H1: The dimensions used to calculate efficiency. (Left) The distance between the extreme edges of the tabletop is the stacking dimension, *d*. (Right) The pictured distance is the stacking space, s_S.

We calculated stacking efficiency through the equation:

$$Stacking\ Efficiency = \frac{d - s_s}{d}$$

Equation H1: Stacking efficiency equation. 100% efficiency equates to no increase in footprint when stacked, and a 0% efficiency means the footprint doubles when stacked.

Figure below correlates stacking efficiency with tabletop thickness, and Figure shows the thickness dimension from a top view.

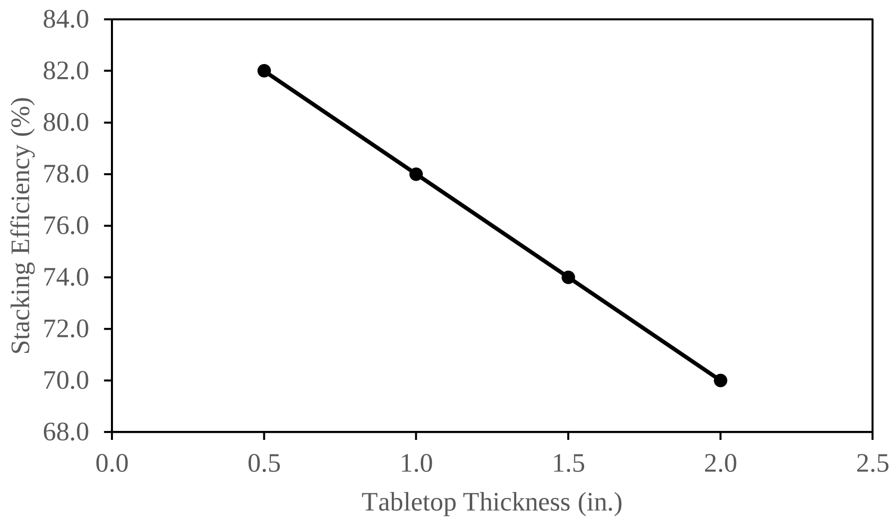


Figure H2: Stacking efficiency correlated to common tabletop thicknesses. Note that tabletop thickness is linearly correlated to stacking efficiency.

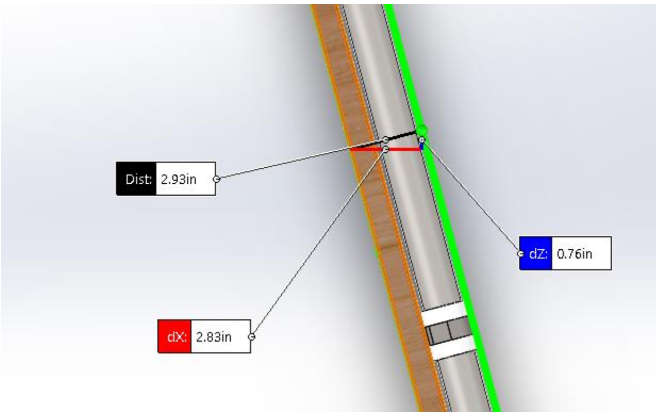


Figure H3: Top view of the folded table. Note that reducing the diameter of the piping will have the same effect as reducing tabletop thickness.

Finally, the data gathered is tabulated in Table below.

Table H1: Tabulated stacking efficiency data as a function of tabletop thickness.

Tabletop Thickness (in.)	Stack Efficiency (%)
0.5	82
1.0	78
1.5	74
2.0	70

We conducted a similar process to determine the stacking efficiency sensitivity to base angle change. The results are given below.

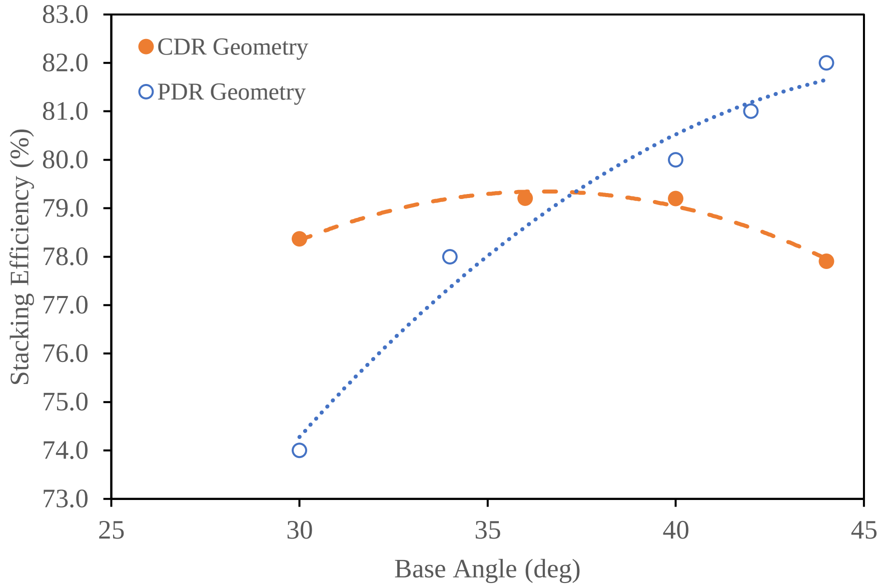


Figure H4: Stacking efficiency as a function of base angle.

Table H2 below contains the tabular data.

Table H2: Tabulated results of the base angle study for PDR and CDR geometries, respectively.

Base Angle (deg)	Stack Efficiency (%)
30	74
34	78
40	80
42	81
44	82
50	84
56	85

Base Angle (deg)	s_s	d	Stack Efficiency (%)
30	13.69	63.28	78.37
36	12.97	62.38	79.21
40	12.83	61.68	79.20
44	13.46	60.91	77.90

Appendix I: Hardware Compatibility Test Report

Structural Prototype (SP Testing: Hardware on Honeycomb Structure paper filled table)

Prototype Goals

This prototype was designed to:

- Prove out the hardware compatibility with honeycomb structure paper filled type of tabletop.
- Determine the sturdiest combination of hardware by performing three tests: Impact test with axial load, Creep test with shear and axial load, and destruction test.

Build Scope

We have a lightweight tabletop from Ikea to be potentially used for our project where the inside of the tabletop consists paper-based filling material. Lightweight feature of this type of the tabletop will make the deploying and folding functionality of our design be done with little effort from the user, but the cavity inside of the tabletop complicates the installation of the hardware that will be connecting the tabletop to the collared hinges. We have created a five different hardware cases to be tested to determine which combination of hardware provide a robust connection. Listed below were the five hardware combinations:

1. Screw eye
2. Screw eye + EZ Ancor hollow door & drywall anchor
3. Screw eye + Everbilt zinc tee nuts
4. Screw eye + EZ Ancor hollow door & drywall anchor + Adhesive
5. Screw eye + Everbilt zinc tee nuts + Adhesive

Both tabletop and the materials that were used in the testing is explained later in the document. These hardware combinations went through a series of testing, which were:

1. Weight-drop test (impact axial load): a 10lb weight, attached on the screw eye, was dropped from 2.5 ft of height. This impact load case is well above the necessary load bearing case for a single hardware and is suitable to simulate a worst-case motion to potentially destroy the mating where a user might snatch open the tabletop and hit the frame while undergoing the folding process. See the testing schematic below.

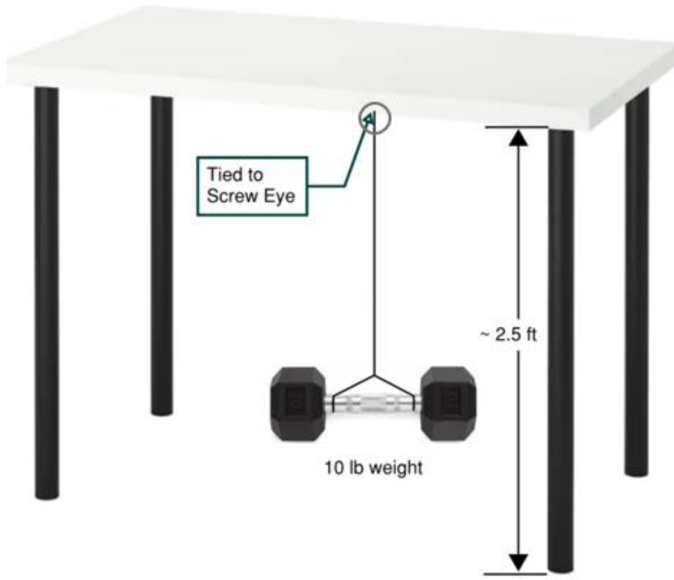


Figure I1: Weight-drop test schematic.

2. Creep test (continuous axial and tensile load): an approximate 15lb weight tabletop was hanged on a bar from the screw eye for a long period of time to apply continuous axial and tensile load on the hardware. This load case simulated the hardware's capability to hold up the tabletop when in folding configuration being stored.

3. Destruction test: destroyed and extracted the hardware from the tabletop by hitting the screw eye with a mallet and taking them out using a plier. Each hardware combinations were ranked as the result of the destructive test based on the effort that have been put in to destroy and extract out the hardware.

Materials

Figure I2: LINNIMON tabletop from Ikea, Fiber + particle board shell with honeycomb paper filling structure / ADILS table leg from Ikea.

Above tabletop from Ikea is called LINNIMON. It is a widely used desk known for its advantage of being economical, extremely light-weight, and having clean surface finish compare to the other desks in the same price range available in the market. LINNIMON tabletop is constructed having a shell of particle board with fiberboard surface with cardboard paper filling to fill the cavity of the shell. The carboard paper filling material is in a shape of honeycomb to enhance the rigidity of the tabletop and resist bending. Light-weight feature of the LINNMON table is achieved with cardboard paper filling structure, however joining the necessary parts, such as hinges, to the tabletop gets complicated as the tabletop has a thin rigid portion of the body capable of holding the joining hardware. Goal of this structural prototype testing was to resolve this issue by utilizing one of the possible hardware candidates introduced below.

Table legs in the figure above are the attachable item that are designed to be compatible with the testing LINNIMON tabletop from Ikea. Installing the table legs on each side of the tabletop provided the height of 2.5 ft that was necessary to attach the hardware combinations and to drop the weight to simulate impact loads.

Following materials were used for the hardware testing.

Figure I3: Everbilt zinc tee nuts.

Above hardware is called tee nuts, where it is used to mostly fasten a wood with a flushed surface. Per the manufacture’s recommendation on the label, tee nuts shall be simply hammered down to the desired fastening location on a wooden surface to be installed. Above #6 Everbilt zinc tee nuts were purchased from Home depot.

Figure I4: EZ Ancor hollow door & drywall anchor.

Above hardware is called drywall anchor, where it is also used to mostly fasten a wood with a flushed surface. We have decided to test out the metal anchors instead of the plastic anchors, assuming we would have more durability and be more robust. Per the manufacture's recommendation on the label, drilling will not be necessary to install and shall be simply be self-tapped on the desired location with #2 Phillips screwdriver. Above #6 EZ Ancor hollow door & drywall anchors were purchased from Home depot.

Figure I5: Gorilla super glue adhesive.

Above is the adhesive that was used for the hardware testing. These are Gorilla brand superglue where per the manufacture is recommended to be used on the wooden surfaces. Adhesive were used on the mating surfaces between the tee nuts and the drywall anchor to the tabletop to potentially provide more rigid joining for the hardware to better withstand the testing loads.

Figure I6: Everbilt Screw eyes #6.

Above hardware is called screw eyes which will be installed on the tabletop barely, with a tee nut, and with a drywall anchor. Purpose of using the screw eyes for this testing instead of the regular screw is to have a portion of the screw that is available to be tied on with a fabric cord which will hang the weight that will be dropped from certain height to cause the axial impact load on the mating surface. Installing of the screw eye does not require tool but simply are hand-tightened.

Figure I7: 10 lb. weight to be dropped to create an impact load.

Above weight is use for the first test: weight-drop test. To be attached to the screw eye in the hardware, fabric cord wrapped around both side of the weight for balance and was tied up on the screw eye.

Test Procedure

Below is the step-by-step testing procedure to analyze the compatibility of each hardware combinations.

1. Install 1 Everbilt Screw eyes #6 in a pre-drilled hole on a bottom surface of the LINNMON tabletop; location of the installation shall be preferably around the centroid of the tabletop.
2. Install 4X ADILS table legs to the LINNMON tabletop.
3. Conduct Test #1: Weight-drop test – tie up the 10lb weight on the hardware using the fabric cord and drop the weight at a height of 2.5 ft, which is the height where the weight would make a contact to the bottom side of the tabletop.
4. Conduct Test #2: Creep test - using the same hardware from the previous step, tie up the tabletop on a bar using the fabric cord and let it sit stationary for at least an hour. If the hardware failed Test #1, do not proceed with Test #2 and #3.
5. Conduct Test #3: Destruction test – using a mallet, hit the screw eye to destroy the mating. Extract out the hardware using a plier.
6. Install a hardware combination of Screw eye #6 + EZ Ancor hollow door & drywall anchor in a pre-drilled hole on a bottom surface of the LINNMON tabletop; location of the installation shall be preferably around the centroid of the tabletop. Use #2 Philips Screw driver to install the EZ Ancor and hand tighten the screw eye to the EZ Ancor.
7. Do Steps 3 to 5 for hardware combination: Screw eye #6 + EZ Ancor hollow door & drywall anchor.
8. Install a hardware combination of Screw eye + Everbilt zinc tee nuts in a pre-drilled hole on a bottom surface of the LINNMON tabletop; location of the installation shall be preferably around the centroid of the tabletop. Use a mallet to install the Everbilt zinc tee nut and hand tighten the screw eye.
9. Do Steps 3 to 5 for hardware combination: Screw eye + Everbilt zinc tee nuts
10. Do Steps 6 to 9 again but apply Gorilla brand super glue when installing the hardware initially.
11. Record the results of the testing in the result table.

Result / Analysis / Conclusion

1. *Bare screw eye*

Figure I8: Bare Screw eye hardware installed in a pre-drilled hole.

This is the manufacture's method of installing hardware on the LINNMON tabletop. This method of hardware showed a passing results for testing # 1 and 2, however we wanted to avoid this installation as screwing the hardware back in the same hole after it is taken out for maintenance will won't provide the same snug fit from the initial installation.

2. *Screw eye + EZ Ancor hollow door & drywall anchor*

Figure I9: EZ Ancor drywall Anchor installed with a screw eye.

EZ Ancor drywall Anchor performed the best among the other method in the series of testing. Fitting on the tabletop was sturdy without wobble and passed both weight-drop and hanging test. While the anchor was getting screwed into the tabletop, particleboard residue squeezed out around the border of the anchor and made the mating aesthetically unpleasing.

3. *Screw eye + Everbilt zinc tee nuts*

Figure I10: Everbilt zinc tee nut installation failure.

Figure above shows incompatibility of the Everbilt tee nut to the particle board material of LINNMON tabletop. While getting hammered in to the surface to be installed, region around the installation started to rupture as one piece and did not provide a sturdy connection at all.

4. *Screw eye + EZ Ancor hollow door & drywall anchor + Adhesive*

Figure I11: EZ Ancor installed with adhesive.

Figure I12: EZ Ancor installed with adhesive destructive test.

Above figures show the EZ Ancor drywall anchor installed on the tabletop with Gorilla brand super glue as an added adhesive. To improve from the issue we had from hardware case 2 where the particleboard residue squeezed out, the residue was cleaned with a X-ACTO knife to be more aesthetically pleasing. **Error! Reference source not found.** shows the result of the destructive test of hardware case 4.

5. *Screw eye + Everbilt zinc tee nuts + Adhesive*

This hardware case was not tested as case 3 of Everbilt zinc tee nut failed during the installation process.

Table I1: Compatiability test results.

Hardware Combination	**Hand pull (Pass / Fail)**	**10lb @ 3ft (Pass / Fail)**	**Destructive Test (ranked)***
1. Screw	Pass	Pass	3
2. Screw + EZ Ancor hollow door & drywall anchor	Pass	Pass	2
3. Screw + Everbilt zinc tee nuts	Fail	Fail	5
4. Screw + EZ Ancor hollow door & drywall anchor + Adhesive	Pass	Pass	1
5. Screw + Everbilt zinc tee nuts + Adhesive	Fail	Fail	4

*Most robust combination of hardware was ranked the highest

Table above has a collectable test results of the hardware candidates. Results have shown that the hardware case #4, **Screw + EZ Ancor hollow door & drywall anchor + Adhesive**, shall be used to connect the hinges to the tabletop as it is shown in the testing results.

Appendix J: Table Tipping Calculations

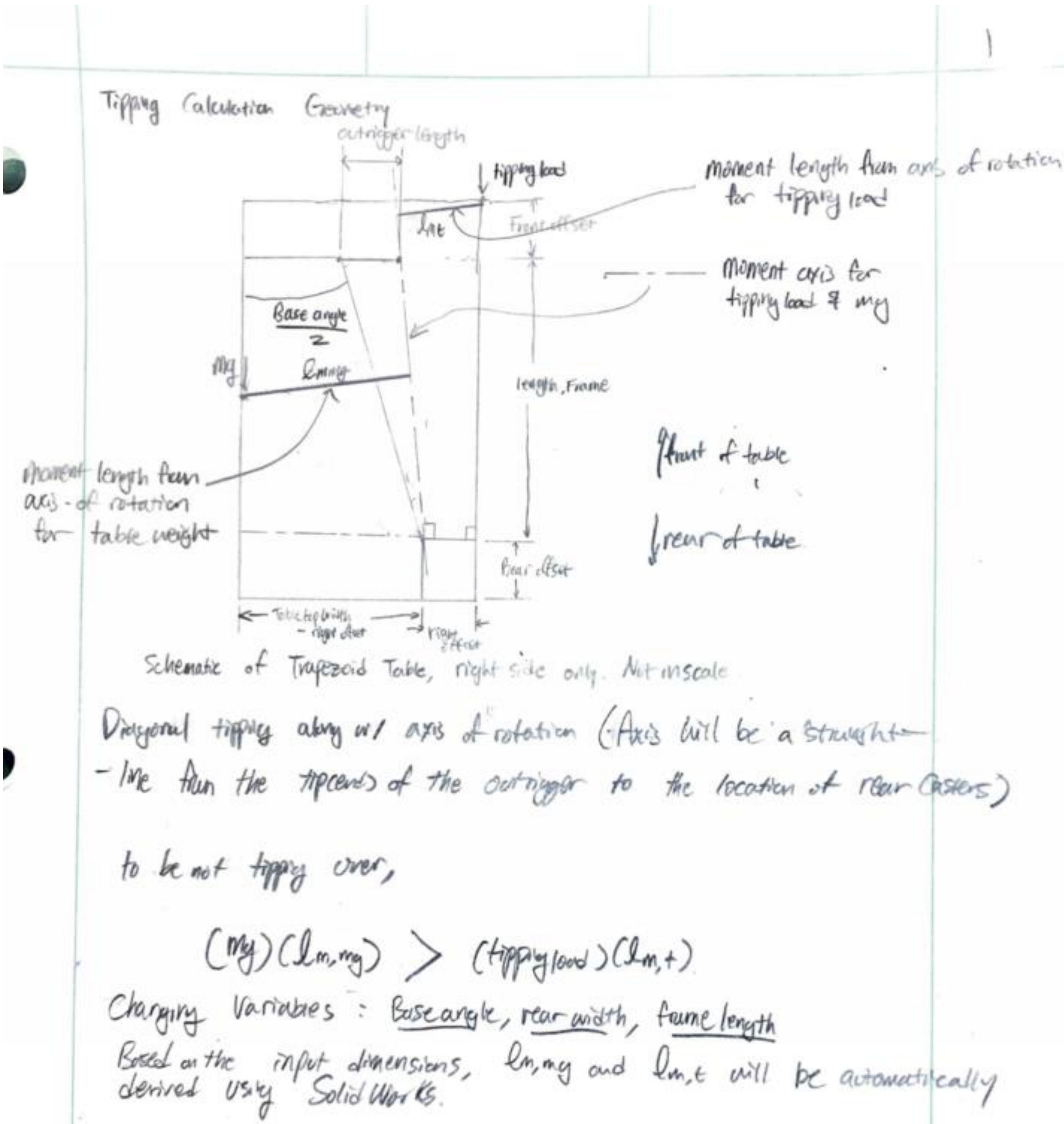


Figure J1: Diagonal tipping calculation methodology.

Trapezoid Table — Tipping Calculation

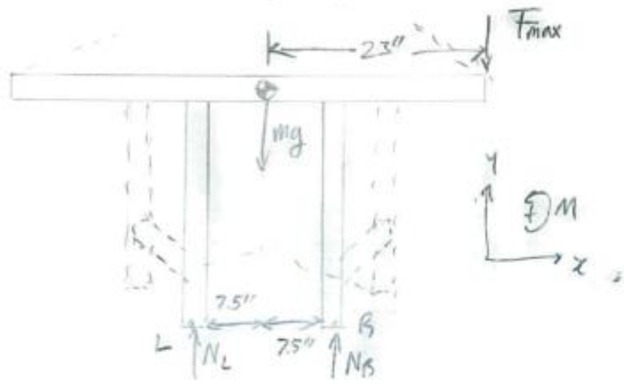
Given: Table dimensions,

Find: Maximum tipping load, F_{max}

assume:

- N_L, to be 1 lb having a small normal load simulating the table in the verge of tip
- all weight of the table is point mass @ Center of assembly (110 lb)
- 125 lb Concentrated load is a point load @ the very end of the table
- no horizontal forces
- Only front view of the assembly

Solve:



FBD of Table

- Moment @ B to find F_{max} (normal load on Front-Right-leg)

$$-15''(N_L) + 7.5''(mg) - (23''-7.5'')F_{max} = 0$$

$$\Rightarrow -15''(1\,lb) + 7.5''(110\,lb) - 15.5''F_{max} = 0$$

$$\Rightarrow -15.5''F_{max} = -810\ in\text{-}lb$$

$$\Rightarrow F_{max} = \boxed{52.2\ lb}$$

Relationship between weight and Max tipping load

$$\Rightarrow \boxed{F_{max} = 0.484\,mg - 0.968\,lb}$$

Figure J2: 2-D Front side tipping calculation sample.

Inputs:

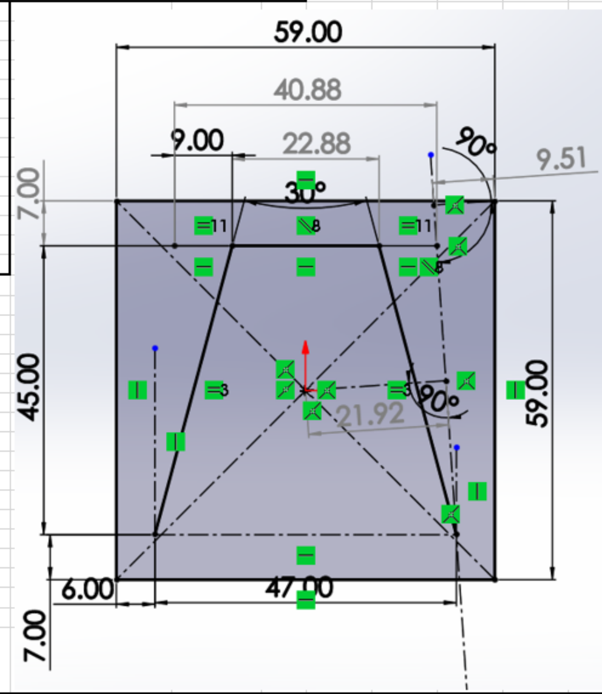
		Units			Units			Units
Frame:			Table top (LINNMON 59x29.5):			Calc references:		
Base Angle	30	degrees	T Length	59	in	Front offset	7	in
Rear Width	47	in	T Width	29.5	in	Rear offset	7	in
Front Width	22.88	in	T thickness	1.375	in	Left offset	6	in
Height	26.22	in	App. Density	0.0089	lb/in3	Right offset	6	in
Length	45	in				Side length	52.0	in
Pipe OD	1.25	in				**Tipping load**	125	lbf
Pipe ID	1.185	in				Density of Steel	0.284	lb/in3
Rigger Width	9	in				Pipe cross-section area	0.124308894	in2
Tip Front Width	40.88	in						

Outputs:

Weights:		
2X Tabletop weights	42.55	lbf
Frame:		
4X Leg volume (steel)	13.04	in3
4X Leg weights	3.70	lbf
2X front volume	7.93	in3
2X front weight	2.25	lbf
4X Side volume	25.84	in3
4X Side weight	7.34	lbf
SUM: 1X Frame weight	13.29	lbf
Total Assembly Weight	55.84	lbf

Tipping case:

Diagonal Tipping Case:		
		Units
length,mtip (SOLIDWORKS)	9.51	in
length,mmg (SOLIDWORKS)	21.92	in
Moment,tip (diagonal)	1188.75	lbf-in
Moment,mg (diagonal)	1223.95231	lbf-in
2-D Front Tipping Case:		
Moment,tip (2-D front)	1132.214207	lbf-in
Moment,mg (2-D front)	2282.881714	lbf-in
Table tip (diagonal)?	**NO tip**	
Table tip (2-D Front)?	**NO tip**	



Notes:

1. Decreasing base angle will increase front width and the tipping stability
2. Dimension from front side to rear side (Frame Length) will be stationary.
3. Assuming the mate between two table top is closed-tight.

Figure J3: Snapshot of final tuned frame geometry with no tipping.

Appendix K: Hinge Test Report

Prototype Goals

This prototype will be designed to:

- Prove out the UHMWPE manufacturing process.
- Test clearances between part and frame tube to ensure consistent turning resistance and slop-free fitment.
- Determine necessary hinge thickness (thin collar vs. long collar).

Our secondary goals (if time allows) will be to:

- Test the wear resistance of the assembly over time.
- Compare the manufacturability and functionality of multiple variations of hinge design

Build Scope

We will build two full-size hinge assemblies to simulate the final hinge subassembly that will eventually be attached to the tabletop.

Materials

- UHMWPE Bushing Blocks
- Bushing Bracket (sheet metal)
- Surrogate Tabletop (2x4 or >1/2" plywood)
- Wood Screws

The hinge design consists of a split bushing fit around the frame tube, fixed to the tabletop via a strap or bracket.

This split bushing must minimize slop, working in tandem with the tabletop locking mechanism to provide a wobble-free user experience when deployed. It must be durable, able to withstand many years of student usage and occasional abusage. It should also provide a consistent user feel, without much stiction, squeaking, or vibration. Finally, the bushing must be made from an inexpensive material to keep overall costs down. Our advisor recommended ultra high molecular weight polyethylene (UHMW) as a bushing material for its natural lubricity with metal; we researched several related plastics before arriving at a final decision.

Figure J1 below depicts the Pugh matrix we used to determine the best material for the hinge. Though acetal seems to present a better option than UHMW, it is almost three times the price. HDPE is an overall comparable material, but UHMW has favorable lubricity. Therefore, it will be our choice going forward.

		Alternatives				
Criteria	Ultra High Molecular Weight Polyethylene (UHMW, Tivar)	Acetal	High Density Polyethylene (HDPE)	Nylon	PTFE (Teflon)	Nylatron (MDS-filled Nylon)
Cost	0	–	+	–	–	–
Dimensional Stability	0	+	–	+	–	+
Strength	0	+	+	+	–	+
Creep	0	+	0	0	–	0
Moisture Swell	0	+	+	–	0	–
Lubricity	0	0	–	–	+	0
Abrasion Resistance	0	0	–	–	–	–
	0					
	0					
	Totals	3	0	-1	-4	-1
	Rank	1	2	3	4	3

Figure K1: Pugh matrix to determine the relative performance of various plastics.

Test Overview

The first important element of this test will require us to manufacture the UHMWPE collars in two different methods. For the first method we will construct the collars (as modeled in the CAD) out of two half circles (one inch thick) that would fit between the 1.25" OD of the pipe and the pipe strapping. These would be roughly 0.25" in thickness and would be used in the assembly to assess fits as well as wear over time and ease of hinge operation.

We will also be manufacturing a hinge bushing from a process that we believe to be easier, with less potential for error and therefore much more reproducible for a final design. First we will cut the UHMWPE sheet into strips that are as wide as we require the square pipe strapping to be (2" for this case). We will then make a square cut down the middle of this that is nominally 1.25" wide and .625" deep. These cut strips can then be cut to whatever width we require (we plan to experiment with various options from 1 to 3" and combined to form a square bushing that will contact the circular steel tube in four places and mate with a square pipe strapping. A brief overview of the manufacturing process is as follows, starting from a 12" square plate of 1" thick UHMWPE:

- Cut plate into 1" x 2" blocks.
- Using a router with a square cutting head, cut a 1.25" x 0.625" deep channel through the center of the block.
- Using a chamfer bit, chamfer the outside edges 0.3" in.

Figure J2 below shows a finished bushing. Note the small hole in the part to accept a retaining pin.

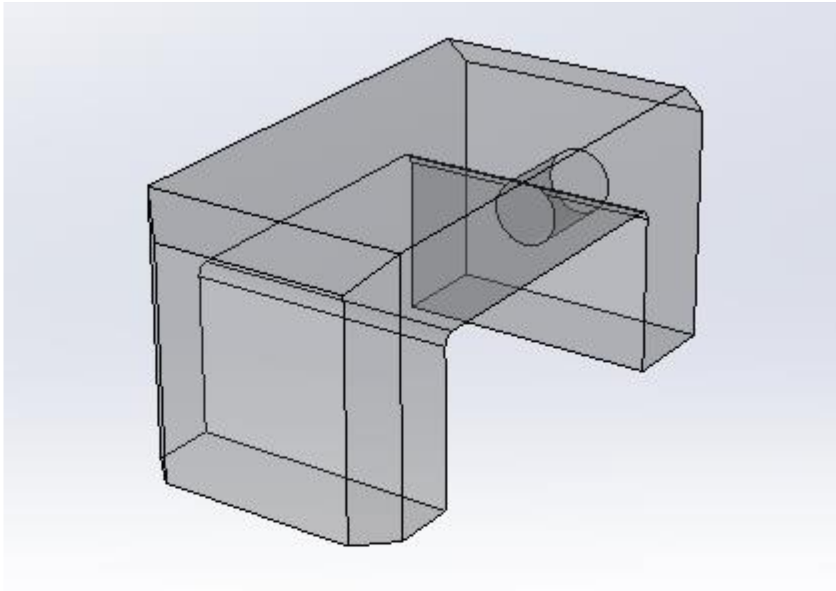


Figure K2: Test square bushing.

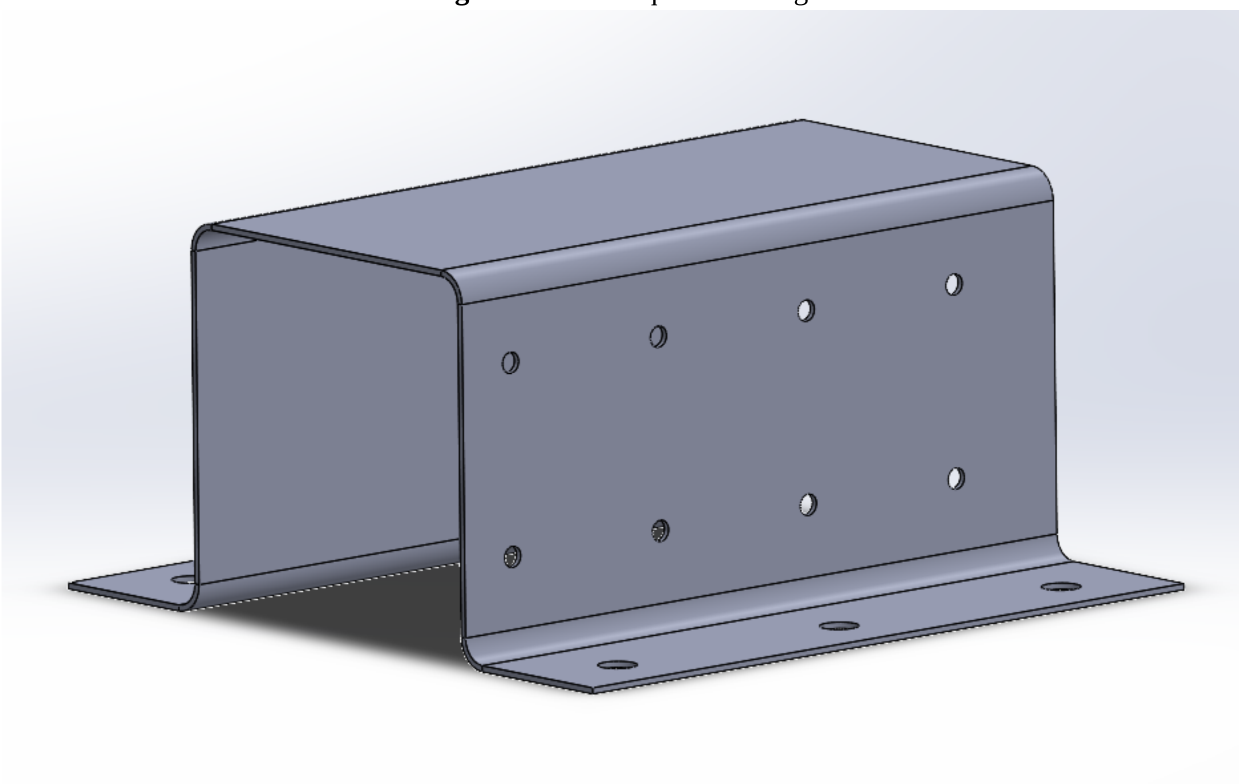


Figure K3: Test square bushing carrier.

To prove out the dimensions for the final design, we plan to make these multiple of these bushings dimensioned with slightly different tolerances in mind so that we can compare how well they fit and how easily the hinge operates with them. The hinge dimensions that provide a snug fit while still facilitating an easy to operate hinge motion will provide the insight we need to finalize tolerance dimensions of the hinge collar drawings. Figure J3 above shows our test bushing carrier, able to accept several bushings at once.

To understand the wear characteristics of the bushings, we will conduct a partial life test. For an arbitrarily-set life cycle, we estimated the usage load in Table 1 below. One cycle is as follows:

- 90° clockwise rotation
- 90° counterclockwise rotation
- 12in. inward slide
- 12in. outward slide

Table K1: Desired life test parameters.

Desired life	15 years
Est. weekly cycles	7 cycles
Weeks used/year	40 weeks
Cycles/year	280 cycles
Desired test life	10%
# of test cycles	420 cycles
Table Weight	20lbs.

Test Procedure

Manufacturing

1. Measure at least 5 spots along the metal pipe to quantify OD dimension and tolerance.
2. Manufacture (2) test square bushing carriers from 0.063” sheet metal.
3. Manufacture three sets of square bushings. One set = 4 parts.
    1. One set should have nominal slot dimensions equal to the nominal pipe OD. The second should be dimensioned 0.010” greater than the pipe OD, and the third set should have a 0.010” interference fit with the pipe.
4. Assemble the hinges to a test section of pipe and fit the assembly to a test section of table (a plank of wood is sufficient).

Testing

Begin with a disassembled testing fixture.

1. Note any previously existing wear marks in the bushing blocks.
2. Assemble the test fixture.
3. Note pipe resistance to swinging and sliding.
4. Fix pipe in the jaws of a lathe.
5. Hang weight from table board equal to table weight in Table 1.
6. Spin the pipe back and forth as many times specified in Table 1.
    1. Using full revolutions rather than back and forth swings is also acceptable, at a quarter of the # of cycles specified (i.e. if # test cycles = 1000, 250 revolutions forward and 250 revolutions backward).
7. Slide pipe in and out as many times as specified in Table 1.
8. After test is completed, note any changes in swinging/sliding resistance from before the test.
9. Disassemble testing fixture and note any significant wear in bushings.

Results

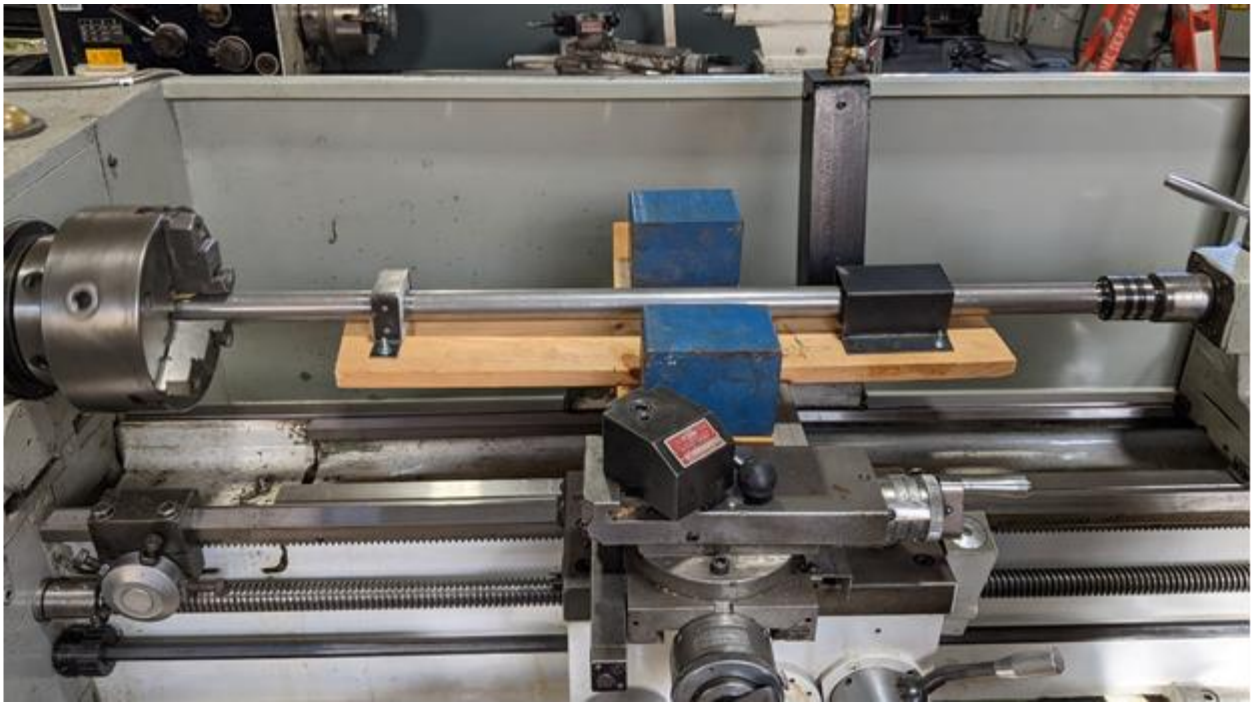


Figure K4: Life testing setup in a lathe.

Figure J4 above depicts our testing setup. The wood board hangs from the pipe, weighting the board with approximately 20lbs. of steel weights. The pipe is free to rotate inside the bushings. Note that “Front” is towards the head stock, and “Rear” is towards the tail stock. “Top” is upwards, “Down” is downwards.

For the first test, we installed bushing set A (.010” interference fit). We began by spinning the pipe 80 times at 80RPM clockwise, followed by the same number of counterclockwise rotations. We repeated this cycle twice. During this portion of the test, we observed no external wear but did note the bushings warmed up slightly. There was no appreciable change in twisting or sliding resistance and the testing was proceeding quickly, so we decided to run 1,250 forward rotations at 125RPM. During this test, the set A bushings increased in temperature by approximately 65°F: the bushings and the pipe’s contact area were too hot to handle after the test. After we observed the wear in set A, we decided to make another set of bushing carriers to try and lower the clamping force on the bushings. We removed the bushings from the test fixture, installed set B (zero fit) along with the looser bushing carriers, and ran the same test. The temperature only increased by 25°F throughout the test.

Figure J5 through Figure J8 below compare bushing sets A and B. A third set of bushings was manufactured with a clearance fit (set C), but was not tested because set B provided satisfactory wear characteristics with zero slop.

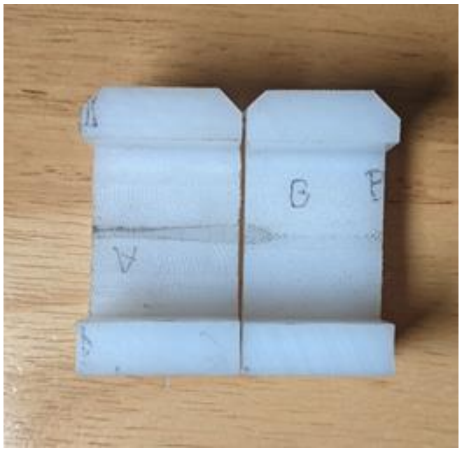


Figure K5: The rear bottom bushings, from sets A and B.

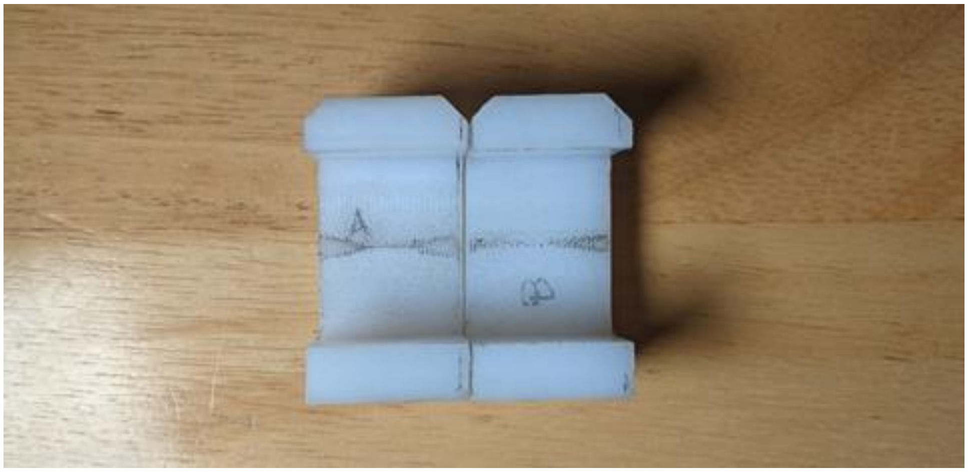


Figure K6: Rear top bushings.

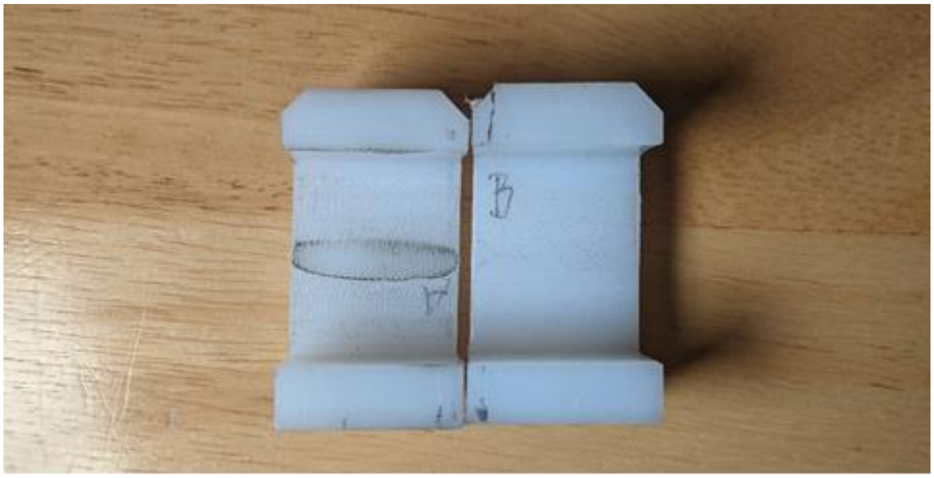


Figure K7: Front bottom bushings. Wear in set A is much more pronounced.

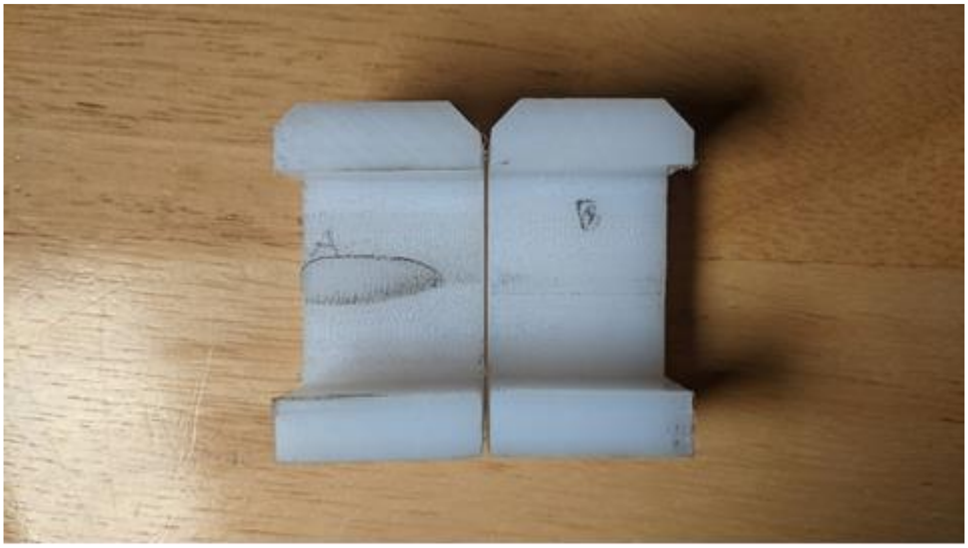


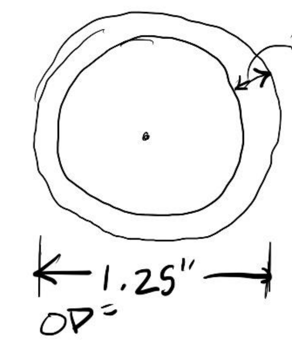
Figure K8: Front top bushings. The carriers changed from set A to B to lower the clamping force.

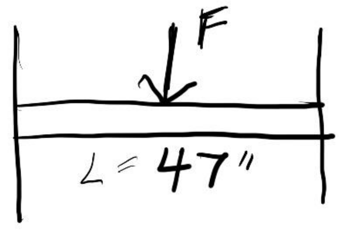
In conclusion, both fits offer acceptable wear characteristics despite striking visual differences. As evidenced above, set A showed much more wear than set B after a total of ~1500 forward and backward revolutions, or ~6000 deploy/stow cycles(almost 1.5x the expected life of the bushings). Neither set developed any slop after this test.

The bushing carriers on set A were slightly undersized, so they put much more clamping force on the bushings than set B. The heightened wear shown above is likely a function of clamping force as well as pipe fit. If this test is repeated in the future, we recommend using bushing carriers more appropriately sized for the parts. The carriers for set B were appropriately sized.

Appendix L: Tube Bending Calculations

Cross-section





Material: A513 steel

Modulus of elasticity: 2.901×10^7 psi

yield strength: 50–60 ksi

$$I_x = 0.0426023 \text{ in}^4$$

For beams w/ a singular center load,

$$\sigma_{max} = y_{max} FL / 4I \Rightarrow \frac{\sigma_y (4I)}{y_{max} L} = F_{max}$$

$$F_{max} = \frac{(50 \times 10^3 \text{ lbf/in}^2)(4)(0.0426023 \text{ in}^4)}{(0.625 \text{ in})(47'' \text{ in})}$$

$$\boxed{F_{max} = 290.06 \text{ lb}_f}$$

If we assume F = 215 (95% weight for 20yo male)

then our Factor of safety = 1.35

For FS requirement of > 1.2, L should not exceed 52.8"

Appendix M: Failure Mode & Effect Analysis

Appendix M: Failure Mode & Effects Analysis

	Components / Function		Potential Failure Mode	Potential Effects of the Failure Mode	Severity	Potential Causes of the Failure Mode	Current Preventative Activities	Occurence	Current Detection Activities	Detection	Priority	Recommended Action(s)
Top Surface	Tabletop	Tabletop / Support user loads	Tabletop breaks	a) user property damaged b) user is injured	5	1) hardware causes damage to wood 2) overload 3) shock load	1) select tabletop with strength to support estimated load 2) load rating displayed under tabletop 3) use inserts 4) reenforce areas with high stress concentration	5	Customer clinic	2	50	
			tabletop bends excessively	a) unable to perform tasks b) user is uncomfortable	9	1) selected tabletop is not stiff enough 2) surface cut too thin	1) weigh users 2) impact factor 3) stress analysis 4) fatigue strength	2	materials testing for different types of wood and thicknesses	2	36	
		Support multiple users	Table is too large	users' communication is impeded	6	user feedback does not reflect population	Acquire variety of user feedback via survey	2	Final group usability test	2	24	
			Table is too small	users are cramped	6	user feedback does not reflect population	Acquire variety of user feedback via survey	2	Final group usability test	2	24	
		Provide smooth surface to write on	Surface gets too hot/cold	User is uncomfortable when touching the table	6	Writing surface material does not insulate	Perform rudimentary thermal testing with material coupons	1	Long-term usage test	2	12	
			Surface is too hard	Writing experience is impeded	6	Writing surface material is too hard	Perform writing test with material coupon	1	Long-term usage test	2	12	
			Surface is too soft	Writing experience is impeded	6	Writing surface material is too soft	Perform writing test with material coupon	1	Long-term usage test	2	12	
	Writing Surface		Surface is damaged	a) User is unable to write smoothly b) sharp edges exposed	7	1) damage from tools 2) Tabletop material is too soft	select durable material	3	material testing of different types of wood	3	63	
			Surface is warped	a) user is unable to write smoothly	6	1) moisture barrier failure 2) table is assembled before wood has dried/seasoned	Select durable top surface that will function even when off-flat	2	Rubbing wear testing	4	48	

Appendix M: Failure Mode & Effects Analysis

Top Surface	Locking Hardware	Maintain tabletop deploy angle	Slop in hardware	User may be pinched	9	1) Excessive overloading 2) inaccurate hardware installation	Perform load calculations to ensure hardware is placed in lower-load positions and orientations, and is loaded correctly.	5	Long-term usage test	3	135	select hardware with high load capacity and long life. Perform tests before and after integrating it into the system.
			Hardware becomes misaligned	a) User unable to lock table sections together b) writing experience is impeded	6	excessive wear of hinging components	Perform tolerance stackup for custom lock. look at potential selection of easily replaced off-the-shelf locking to avoid this failure mode.	5	worse-case-scenario test to determine how the hardware might misalign	3	90	perform a long tterm usage test of components after assembly. Minimize part customization where possible
			Hardware fails	a) tabletop shifts unexpectedly b) work materials fall c) user is pinched	9	1) Hardware wears down 2) Fasteners strip out	1) select hardware with high load capacity and long design life. 2) allow for easy replacement of locking hardware	2	BIFMA loading test	3	54	
	Bump Stops	Support Tabletop	Bump stops are misaligned	a) Locking hardware is more heavily loaded b) Table fails to deploy fully c) user has difficulty deploying	5	1) Fasteners back out 2) Bump stops ripped off	Use loctite or other method of rotation prevention. Include instructions for periodic maintenance	5	Periodic inspection as per instructions	2	50	
		Maintain tabletop deploy angle			5			5	Periodic inspection as per instructions	2	50	
	Pipe Collar	Move Smoothly	Foreign debris gets into collar	a) more difficult to deploy b) increased wear of the hinge joint	4	table used in extremely dusty or dirty area	lubricate joints and seal them off	5	Periodic inspection as per instructions	3	60	
			Frame and collar have different CTE's		4	Table is used in temperature extremes	Perform thermal expansion calcs	3	Long-term usage test	4	48	
		prevent pinch points	Fingers get caught in sliding action	a) user is pinched	7	1) user places hands too close to collar	Guards around sliding parts and clear pinch point warnings	4	Pinch point warnings	4	112	Install guards to prevent accidental contact with collar
		Support tabletop weight	Pipe collar cracks	a) more difficult to deploy b) increased wear of the hinge tube	4	1) table is overloaded	Clearly display table max load; test max loads with factor of safety	4	BIFMA loading test	3	48	

Appendix M: Failure Mode & Effects Analysis

Hinges	Pipe Strapping	Secure pipe collar to table top	Strapping breaks	a) sharp edges exposed b) table collapses c) user is injured	9	1) material is overloaded 2) fasteners loosen over time	include instructions for maintainence/occasional tightening of fasteners as well as easy replacement for worn pipe strapping	2	Long-term usage test	4	72	
		Support tabletop weight when folded	Strapping breaks or fasteners strip out		9			2	Long-term usage test	4	72	
	Hinge Stops	Maintain table deploy angle	Hinge stops fracture or deform	Bump stops and locking hardware are loaded more heavily	2	Table is overloaded or shock-loaded	Design bump stops to engage before hinge stops; put bump stops on table for both deployment and folding	4	BIFMA loading test	3	24	
		Maintain table fold angle		Tabletop collides with frame uprights	4			4	BIFMA loading test	3	48	
	Upright Legs	Support weight of table	Legs buckle	a) user is injured b) sharp edges exposed	9	1) Excessive load 2) Leg material too weak	Conduct load calculations on joints and tubes	2	Test using BIFMA Loading test	2	36	
Frame	Hinge Beams	Support tabletop weight	hinge beam legs buckle	a) tabletop falls b) sharp edges exposed	7	1) User misuses (accidental impacts)	Conduct load calculations on joints and tubes	2	BIFMA loading test	4	56	
		Allow pipe collars to rotate	pipe collars catch/stick	Table is unable to collapse or nest for transport and storage	3	1) Catch Debris 2) Deformation on beams causing collar to be off-concentric	Add dry lubricant to mating surfaces	6	Periodic inspection as per instructions	3	54	
	Lower Cross Beams	Increase frame rigidity	Cross beams buckle	User is uncomfortable using the table	4	1) Excessive bending loads from standing on cross beams	Load calculations on cross beams	4	Loading test	3	48	
	Paint	Prevent frame rust	Paint chips	Legs are exposed and rust	1	1) Excessive rubbing 2) Impact damage 3) Insufficient coating	Apply thick coating	6	Rubbing wear testing	4	24	

Appendix N: Design Hazard Checklist

Appendix N: Design Hazard Checklist

ME 428/429/430 Senior Design Project January 2021

DESIGN HAZARD CHECKLIST

Team: F31 TransporTable Faculty Coach: Professor Harding

Y	N	
☒	☐	1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
☐	☒	2. Can any part of the design undergo high accelerations/decelerations?
☒	☐	3. Will the system have any large moving masses or large forces?
☐	☒	4. Will the system produce a projectile?
☐	☒	5. Would it be possible for the system to fall under gravity creating injury?
☐	☒	6. Will a user be exposed to overhanging weights as part of the design?
☐	☒	7. Will the system have any sharp edges?
☐	☒	8. Will you have any non-grounded electrical systems?
☐	☒	9. Will there be any large batteries or electrical voltage (above 40 V) in the system?
☐	☒	10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
☐	☒	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
☐	☒	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
☐	☒	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
☐	☒	14. Could the system generate high levels of noise?
☐	☒	15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc.?
☒	☐	16. Is it possible for the system to be used in an unsafe manner?
☐	☒	17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

For any "Y" responses, complete a row in your Design Hazard Plan including (a) a description of the hazard, (b) a list of corrective actions to be taken, and (c) the date you plan to complete the actions.

Figure 3: Design Hazard Checklist

ME 428/429/430 Senior Design Project January 2021

Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
pinch point b/w 2 tabletops at the point where they meet.	-light weight tabletops; a gap occurs when tables are swung down, requires sliding motion; -may add bright color on mated edges w/ user feed back,	May 2021	
The two hinged tabletops are large and move during deploy/stow	-latch must be dettached to begin this action; -provide warning label near latch post production	May 2021	
If people jump on table this could lead to injury	-trust setting/sample population; -provide addition warning label on underside of table to warn against improper use	May/June 2021	

Figure 4: Design Hazard Plan

21

Appendix O: Final Indented Bill of Materials

Appendix O: Final Indented Bill of Material (iBOM)

TransporTable Trapezoid Base Table

Indented Bill of Material (iBOM)

Assembly Level	Part Number	Description					Qty	Unit Cost	Ttl Cost	Source	Part No.	More Info
		Lvl0	*Lvl1*	*Lvl2*	*Lvl3*	*Lvl4*						
0	100000	Final Assy								------		
1	110000		Top Assembly							------		
2	111000			Table Top Assembly						------		
3	111100				Table Top		2	$30.16	$60.32	IKEA	202.511.39	Drilled for anchors
3	111200				Tongue		1		$1.00	custom		routed wood
3	111300				Groove		2		$2.00	custon		routed wood
3	111400				Compression Latch		1		$5.00	Amazon		
3	111500				Wood Anchors		8		$10.00	Home Depot		Subject to change
2	112000			Hinge Assembly						------		
3	112100				Bushing Carrier		1	$11.31	$11.31	Home Depot	13266	Bent sheet metal
3	112200				Bushing Half		1	$29.84	$29.84	Grainger	BULK-PS-UHMW-288	Milled UHMWPE
3	112300				Hinge Screw		8		$3.00	Home Depot		
2	113000			Frame Assembly						------		
3	113100R				Rear Uprights		2	$13.47	$26.94	McCarthy Steel	T2W112065	notched steel tube
	113100F				Front Uprights		2	$13.47	$26.94	McCarthy Steel	T2W112065	notched steel tube
3	113200				Cross Tubes		4	$13.47	$53.88	McCarthy Steel	T2W112065	notched steel tube
3	113300				Front Cross Tubes		1	$13.47	$13.47	McCarthy Steel	T2W112065	notched steel tube
3	113400				Casters w/brake		1	$17.98	$17.98	Amazon	755641589338	
3	113500				Outrigger Cross Bar		1	$13.47	$13.47	McCarthy Steel		
3	113600				Outrigger Leg		2	$13.47	$26.94	McCarthy Steel		
	n/a				Welding				$0.00	In-House		
	n/a				Paint		1	$17.12	$17.12	Home Depot		
3	113800				Bump Stop		1	$11.31	$11.31	Home Depot		Punched/cut steel
3	113900				Caster Plate		1	$18.00	$18.00	McCarthy Steel		
3	113910				Caster Nut		4	$0.01	$0.04			
	Total Parts						**44**		**$348.56**			

Appendix P: Drawing Package

Appendix P: Drawing Package

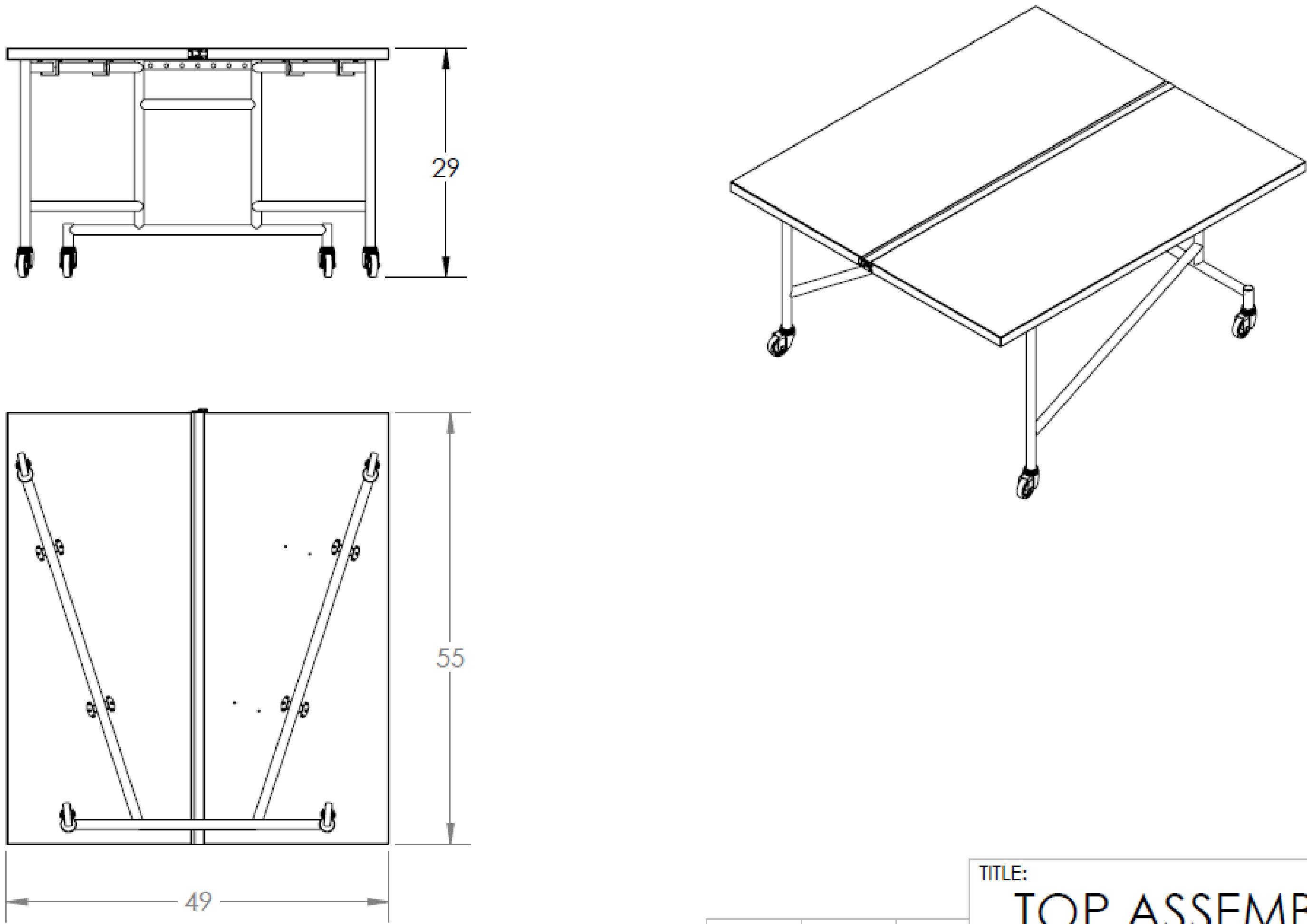
The following is an indented list of all drawings in this package.

110000 – Top Assembly
- **110000E** – Top Assembly, Exploded

111000 – Tabletop Assembly
- **111000** – Tabletop Assembly, Exploded
- **111100** – Tabletop Drawing
- **111100S** – Tabletop Spec Sheet
- **111200** – Tongue Drawing
- **111300** – Groove Drawing
- **111400** – Compression Latch Spec Sheet
- **111500** – Wood Anchor Spec Sheet

112000 – Hinge Assembly
- **112000E** – Hinge Assembly, Exploded
- **112100** – Bushing Carrier Drawing
- **112200** – Bushing Half Drawing
- **112300** – Hinge Screw Spec Sheet

113000 – Frame Assembly
- **113000E** – Frame Assembly, Exploded
- **113100F** – Front Upright Drawing
- **113100R** – Rear Upright Drawing
- **113200** – Cross Tube Drawing
- **113300** – Front Cross Tube Drawing
- **113400** – Caster Spec Sheet
- **113500** – Outrigger Arm Drawing
- **113600** – Outrigger Leg Drawing
- **113800** – Bump Stop Drawing
- **113900** – Caster Mount Drawing
- **113910** – Caster Nut Spec Sheet



	NAME	DATE
DRAWN	D. YANG	6/1/21

COMMENTS:

CHKD: J. KIM 6/2/21

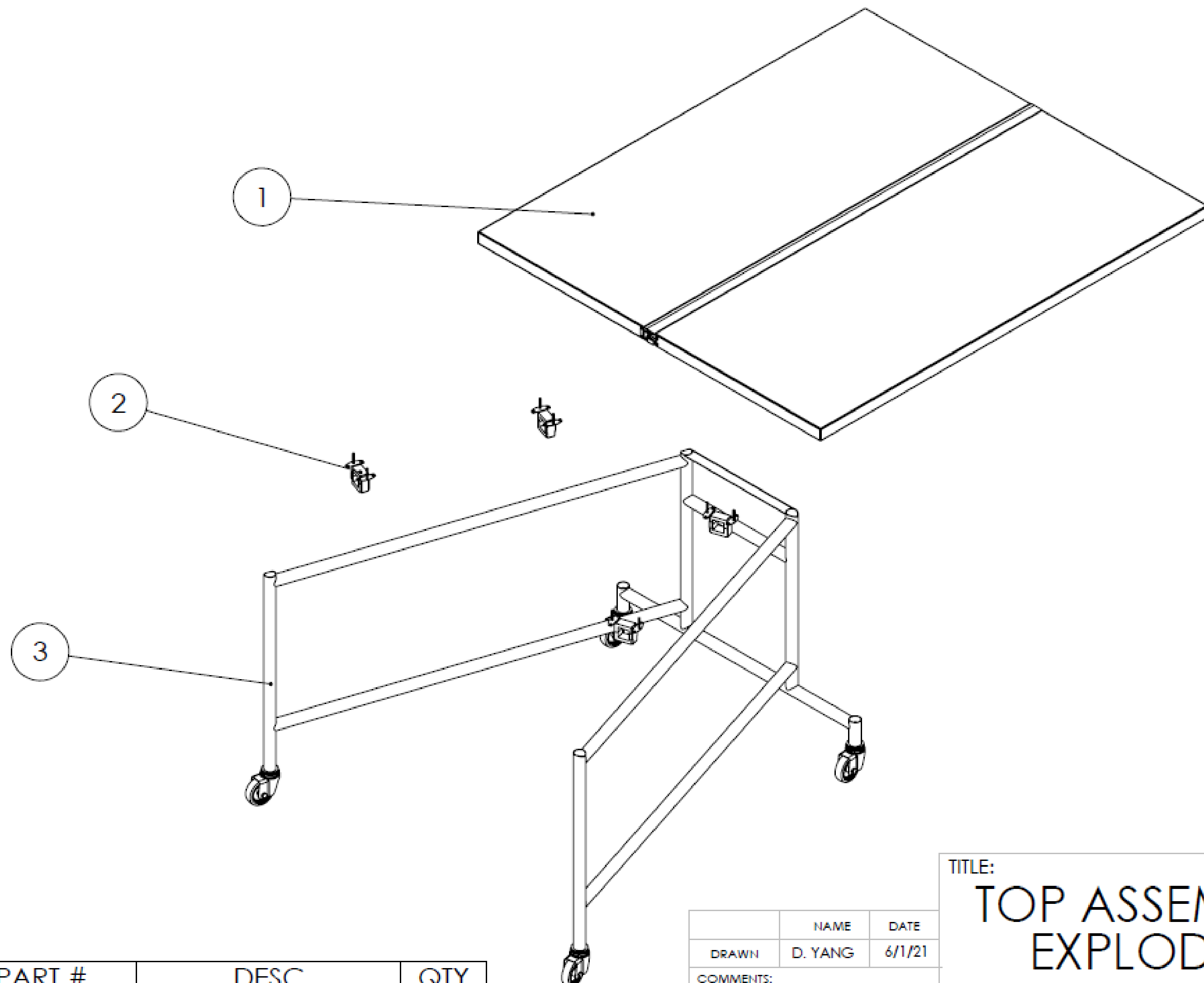
MATERIAL
VARIOUS

DO NOT SCALE DRAWING

TITLE:

TOP ASSEMBLY

SIZE	DWG. NO.	REV
A	110000	B
SCALE: 1:20	WEIGHT: 55LB	SHEET 1 OF 1



#	PART #	DESC	QTY
1	111000	TABLE TOP ASS'Y	1
2	112000	HINGE ASS'Y	4
3	113000	FRAME ASS'Y	1

MATERIAL VARIOUS

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	D. YANG	6/1/21

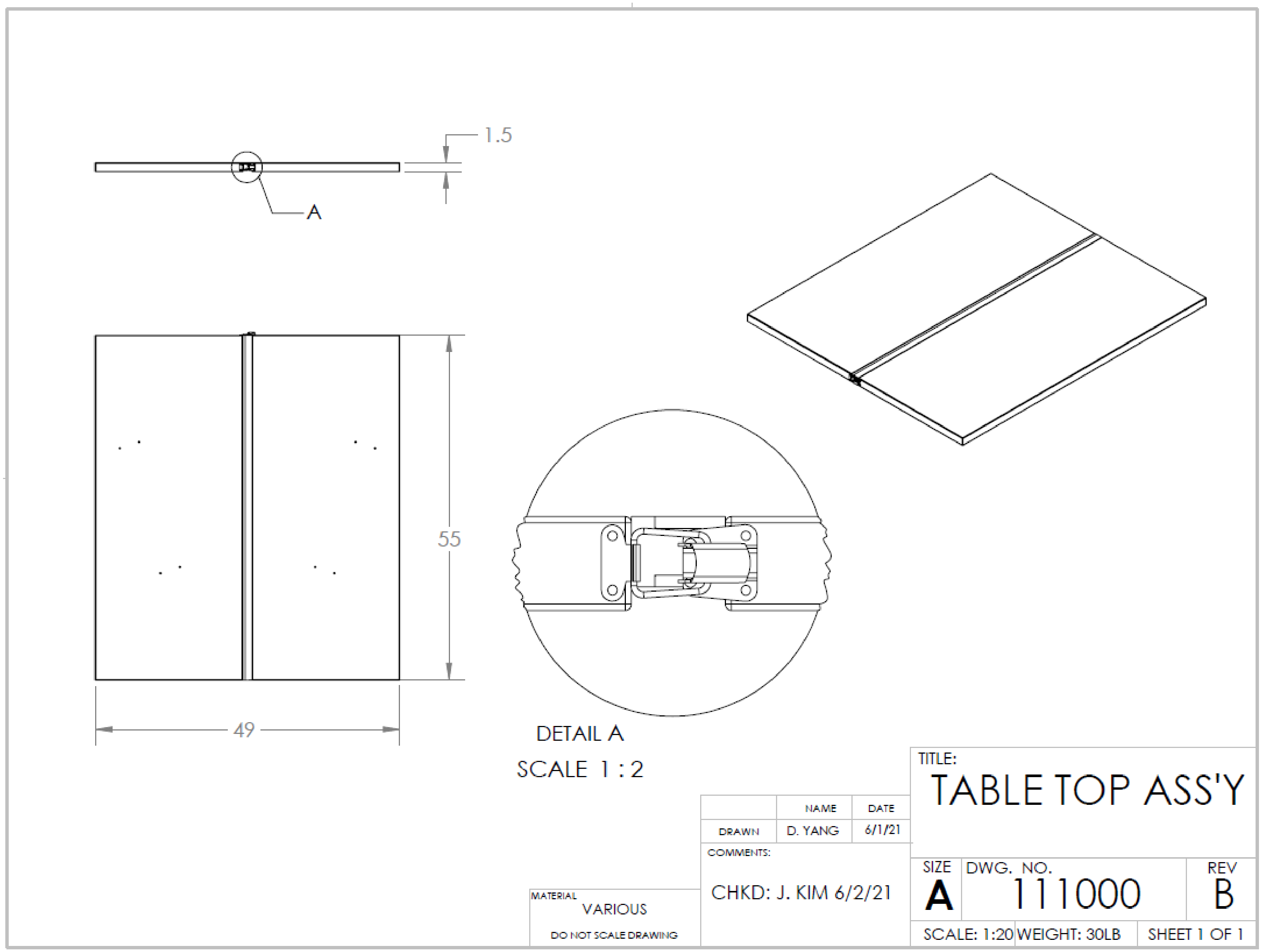
COMMENTS:

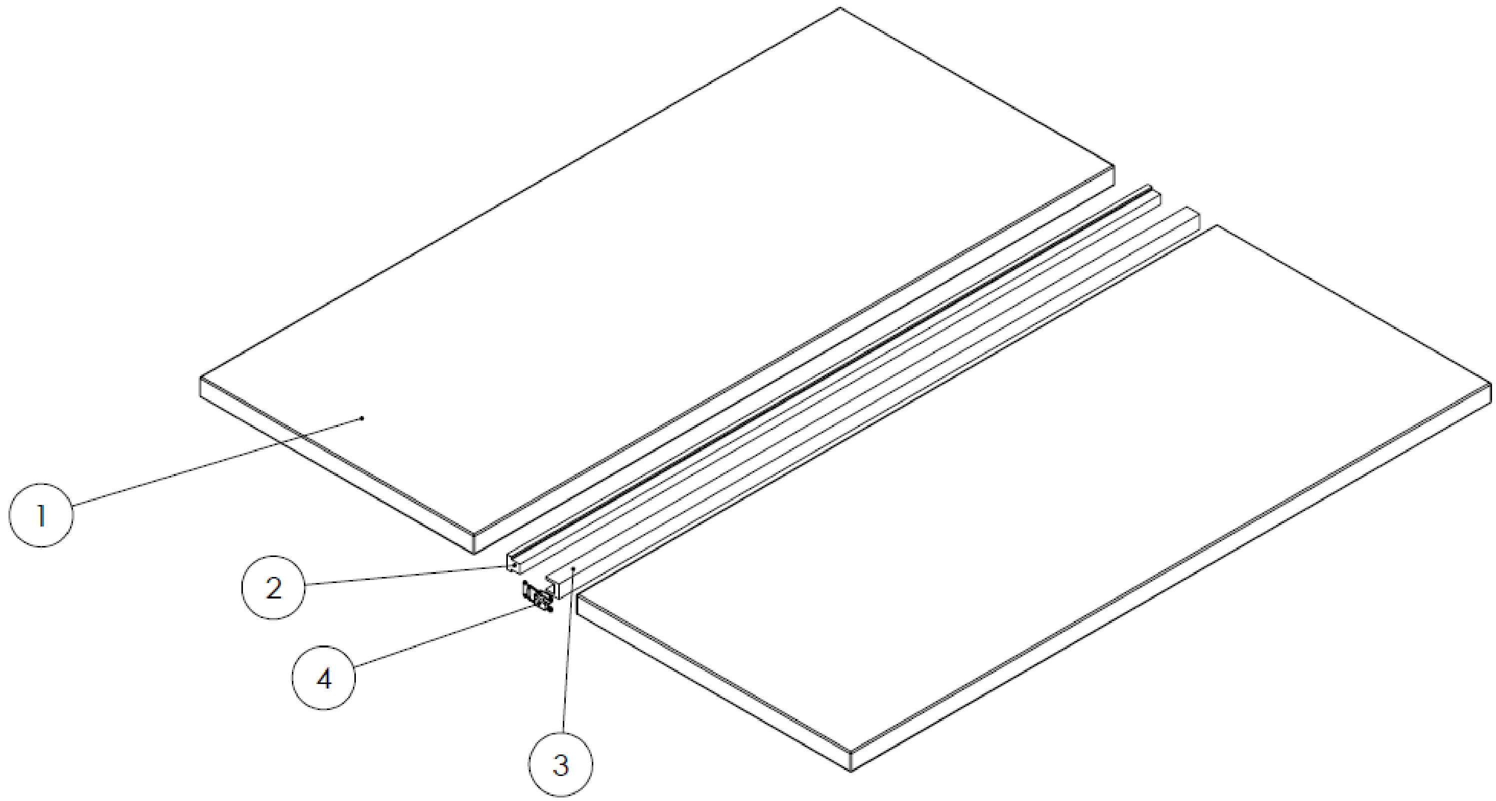
CHKD: J. KIM 6/2/21

TITLE: TOP ASSEMBLY, EXPLODED

SIZE	DWG. NO.	REV
A	110000E	B

SCALE: 1:50 WEIGHT: 55LB SHEET 1 OF 1


1.5
A
55
49
DETAIL A
SCALE 1 : 2
TITLE:
TABLE TOP ASS'Y
NAME
DATE
DRAWN
D. YANG
6/1/21
COMMENTS:
CHKD: J. KIM 6/2/21
MATERIAL
VARIOUS
DO NOT SCALE DRAWING
SIZE
A
DWG. NO.
111000
REV
B
SCALE: 1:20
WEIGHT: 30LB
SHEET 1 OF 1



#	PART #	DESC	QTY
1	111100	TABLE TOP	2
2	111200	TONGUE	1
3	111300	GROOVE	1
4	111400	LATCH	1
5	111500	EZ ANCHORS	8

MATERIAL VARIOUS

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	D. YANG	6/1/21

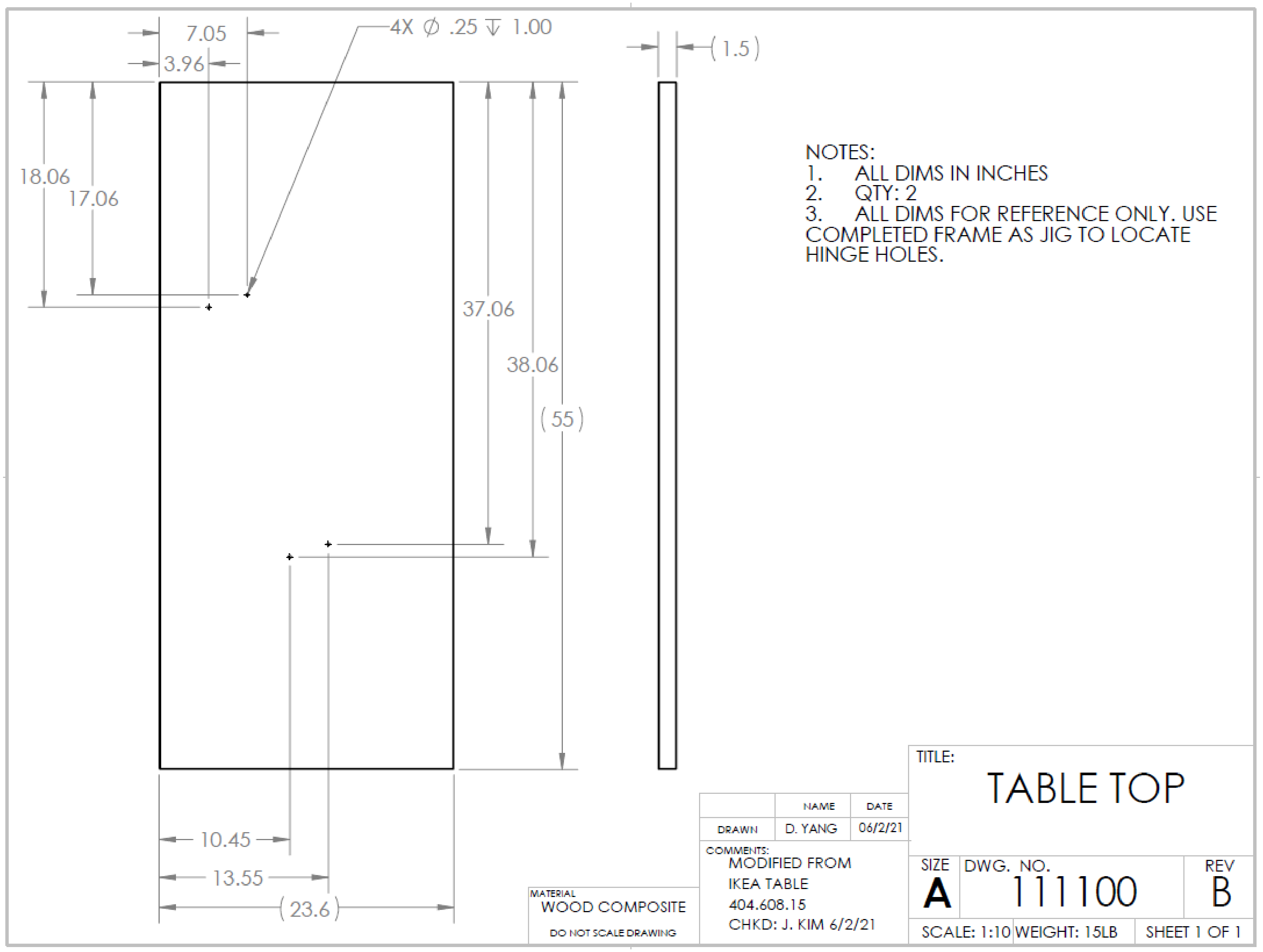
COMMENTS:

CHKD: J. KIM 6/2/21

TITLE: TOP ASSEMBLY

SIZE A | DWG. NO. 111000E | REV B

SCALE: 1:10 | WEIGHT: 30LB | SHEET 1 OF 1


7.05
3.96
4X ∅ .25 ↧ 1.00
(1.5)
18.06
17.06
37.06
38.06
(55)
10.45
13.55
(23.6)
NOTES:
1. ALL DIMS IN INCHES
2. QTY: 2
3. ALL DIMS FOR REFERENCE ONLY. USE COMPLETED FRAME AS JIG TO LOCATE HINGE HOLES.
NAME
DATE
DRAWN
D. YANG
06/2/21
COMMENTS:
MODIFIED FROM
IKEA TABLE
404.608.15
CHKD: J. KIM 6/2/21
MATERIAL
WOOD COMPOSITE
DO NOT SCALE DRAWING
TITLE:
TABLE TOP
SIZE
A
DWG. NO.
111100
REV
B
SCALE: 1:10
WEIGHT: 15LB
SHEET 1 OF 1

New

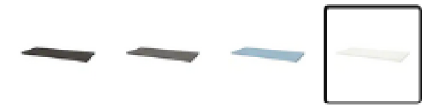
LAGKAPTEN $29.99

Tabletop, white, 55 1/8x23 5/8 "

★★★★★ (8)

Color

White



Add to bag

Available for delivery in select locations

In stock at Burbank, CA

IKEA Product Number: 404.608.15

Length: 55 1/8″

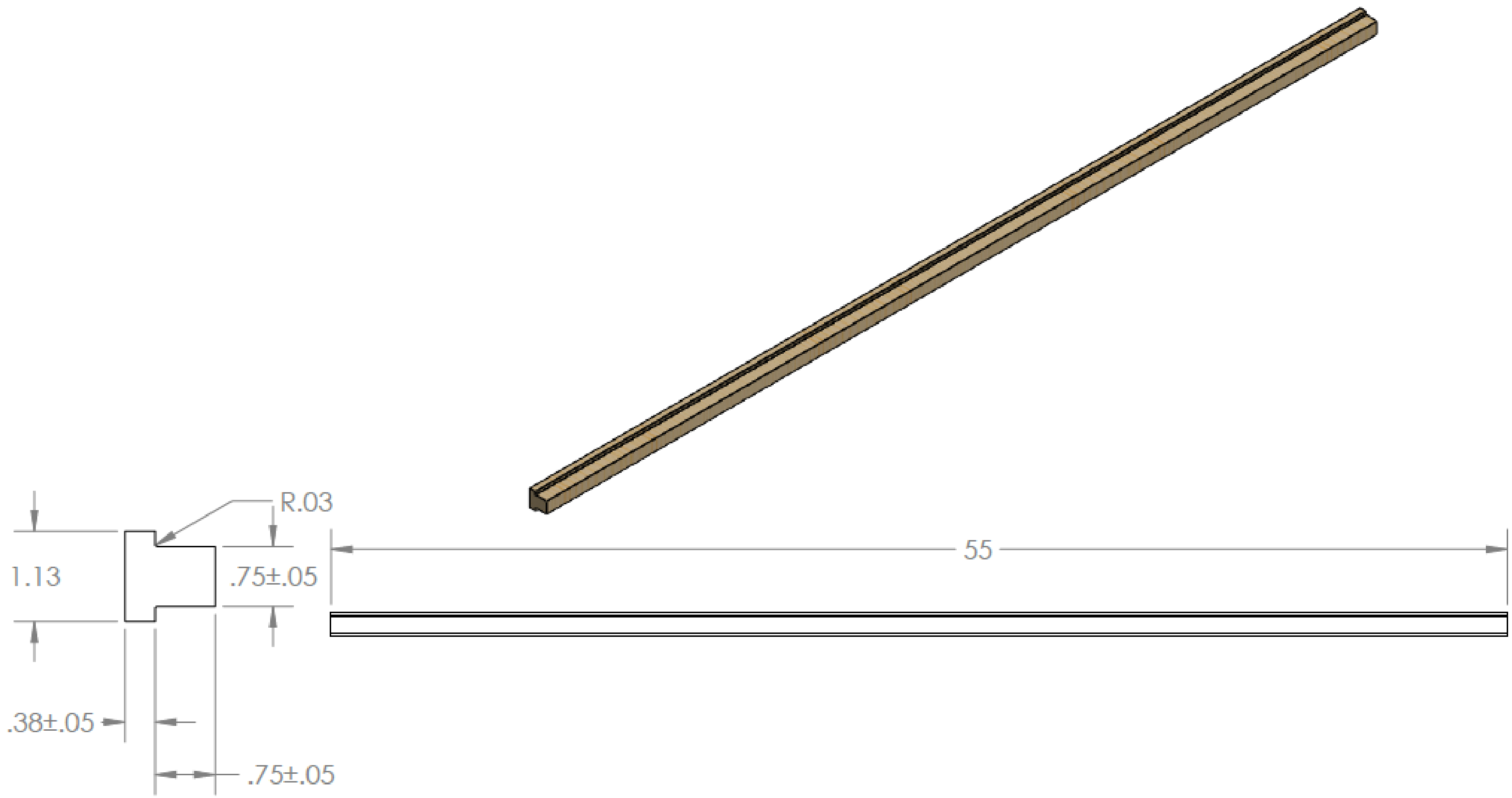
Width: 23 5/8″

Thickness: 1 3/8″

Weight: 18 lb

Construction: **composite coated fiberboard/honeycomb paper sandwich panel**

DRAWING: 111100S



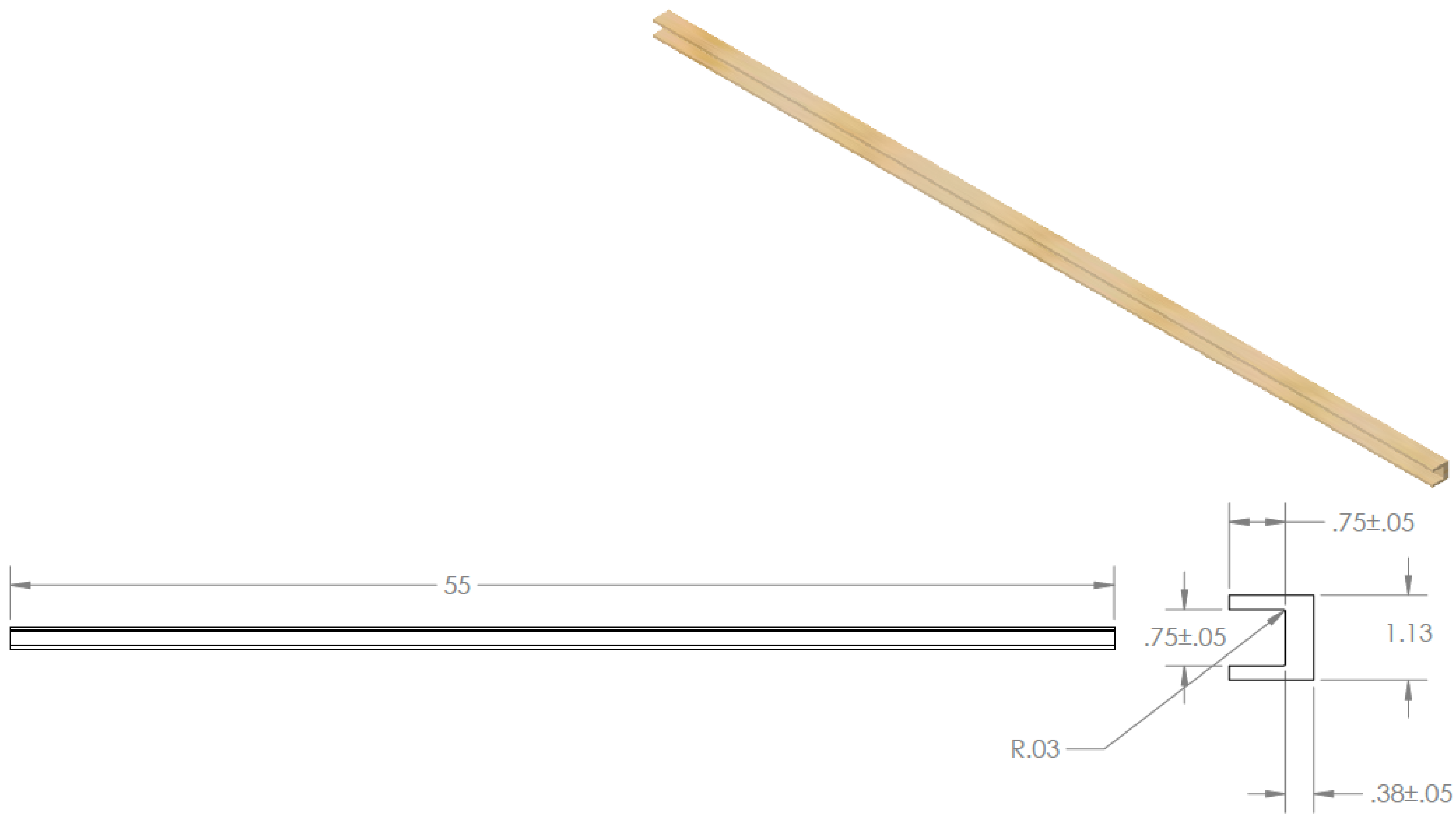
	NAME	DATE
DRAWN	C. MACIAS	6/1/21
CHECKED	D. YANG	6/1/21

COMMENTS:
1.ALL DIMS IN INCHES
2.SYMMETRICAL
4.PART CAN BE SPLIT ALONG LENGTH

TITLE: TONGUE

SIZE A | DWG. NO. 111200 | REV D

SCALE: 1:7.5 | WEIGHT: 2LB | SHEET 1 OF 1



	NAME	DATE
DRAWN	C. MACIAS	6/1/21
CHECKED	D. YANG	6/1/21

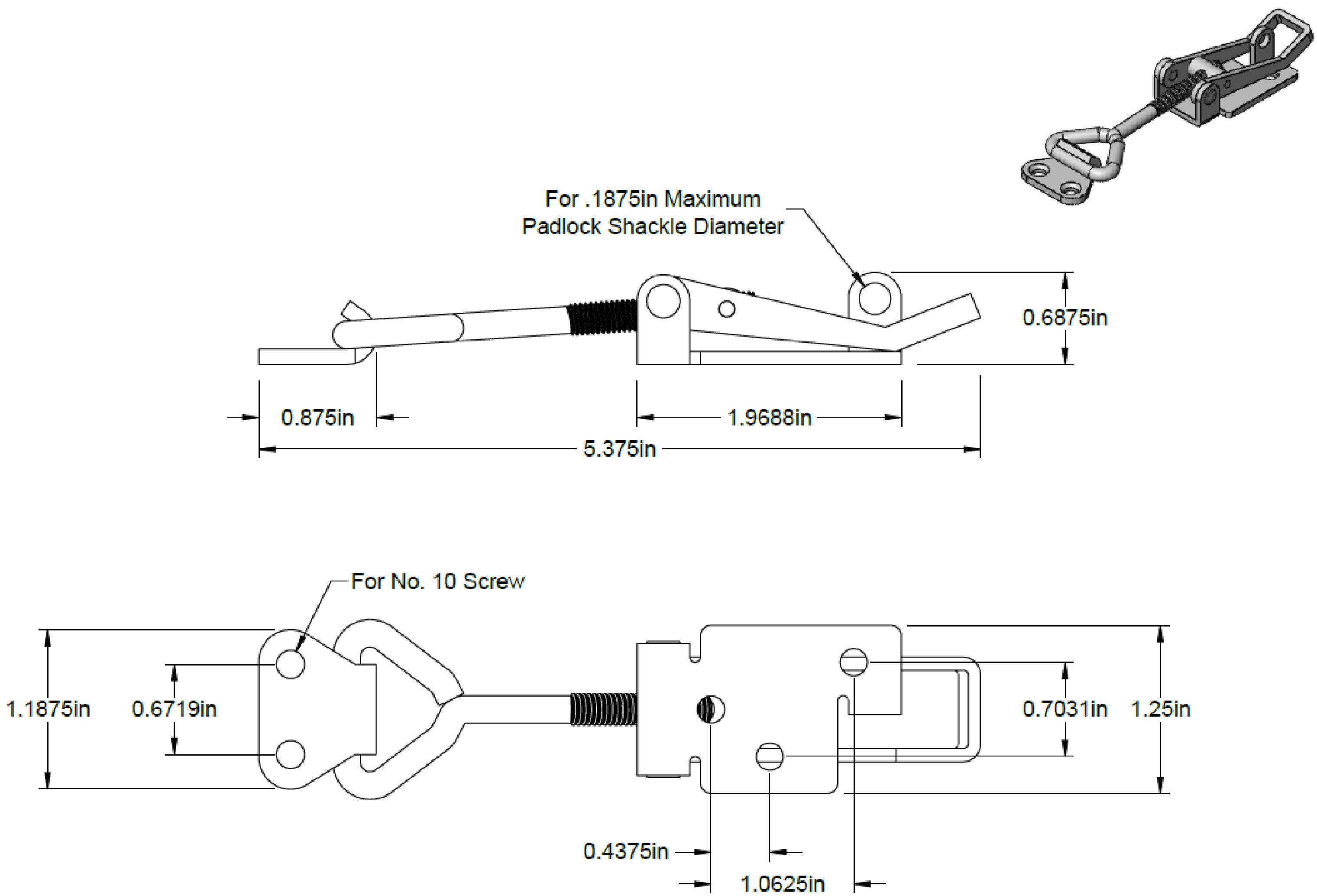
COMMENTS:
1.ALL DIMS IN INCHES
2.SYMMETRICAL
3.PART CAN BE SPLIT ALONG LENGTH

TITLE:

GROOVE

SIZE	DWG. NO.	REV
A	111300	D

SCALE: 1:7.5 WEIGHT: 2 LB SHEET 1 OF 1



Latching Distance: 2in - 2.5in

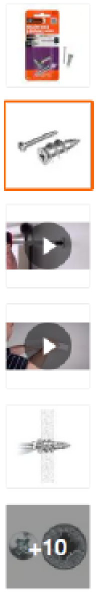
McMASTER-CARR® CAD

PART NUMBER **111400**

http://www.mcmaster.com

Adjustable-Grip Draw Latch

Internet #310450446 Model #25425 Store SKU #1004576923



Hover Image to Zoom

Stud Solver 40 lbs. #6 x 1-1/4 in. Hollow Door and Drywall Anchors (2-Pack)

by **E-Z Ancor** >

★★★★★ (8) Write a Review Questions & Answers (3)

- Anchor easily installs in drywall, even if you hit a wood stud
- Great for handing towel racks, hooks, and pictures
- No pre-drilling necessary, installs with #2 Phillips screw driver
- See More Details

98¢

How to Get It Delivering to: **93405** | Change

Store Pickup	Ship to Home	Scheduled Delivery
Pickup **Today** **FREE**	Not available for this item	As soon as **Tomorrow** **$79.00**

2 in stock at **San Luis Obispo**
Curbside pickup available.
Check Nearby Store

Specifications

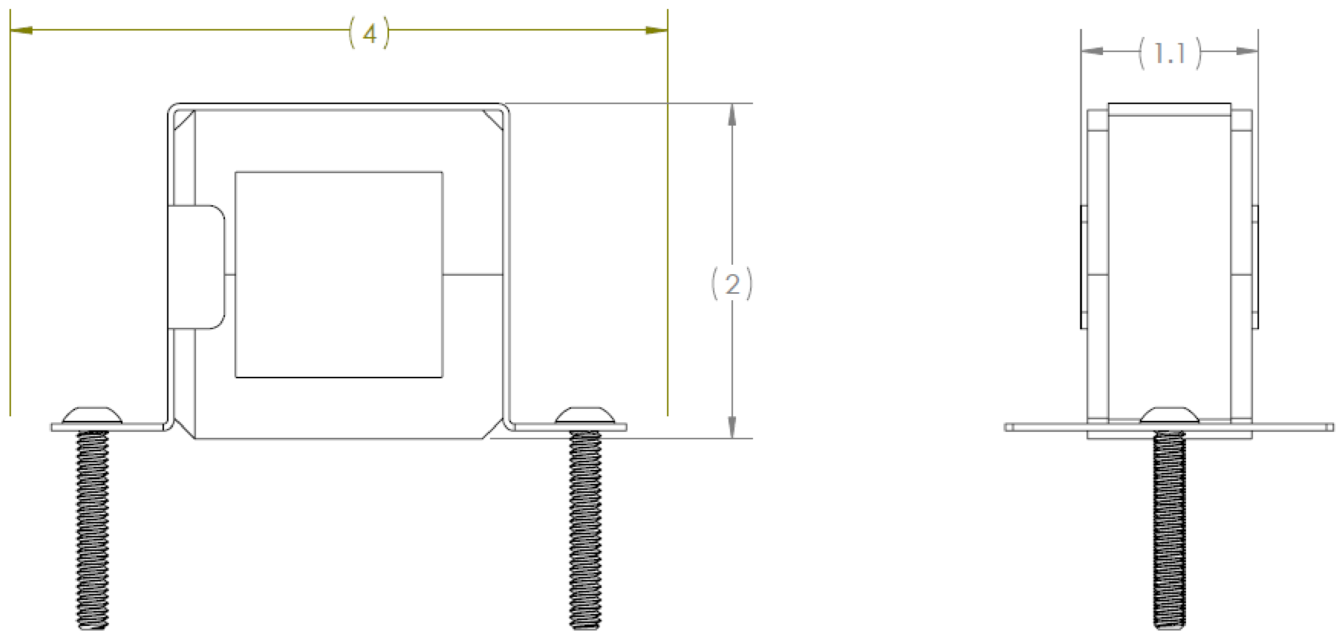
Dimensions

Anchor Diameter (in.)	#6	Anchor Length (in.)	1.25
Required Drill Hole Size (in.)	0		

Details

Color Family	Metallic	Drive Style	Phillips
Fastener Callout Size	#6 x 1.25	Fastener Head Style	Flat
Fastener Plating	Zinc	Fastener Type	Self Drilling Anchors
Fastener/Connector Material	Alloy	Fastening Base Material	Drywall
Features	Coated,Self Drilling	Finish	Zinc
Finish Family	Zinc	Included	Screw
Interior/Exterior	Interior	Maximum Weight Capacity (lb.)	40
Package Quantity	2	Product Weight (lb.)	0.006 lb
Returnable	90-Day	Weight Capacity (lb.)	40 lb

PART # 111500

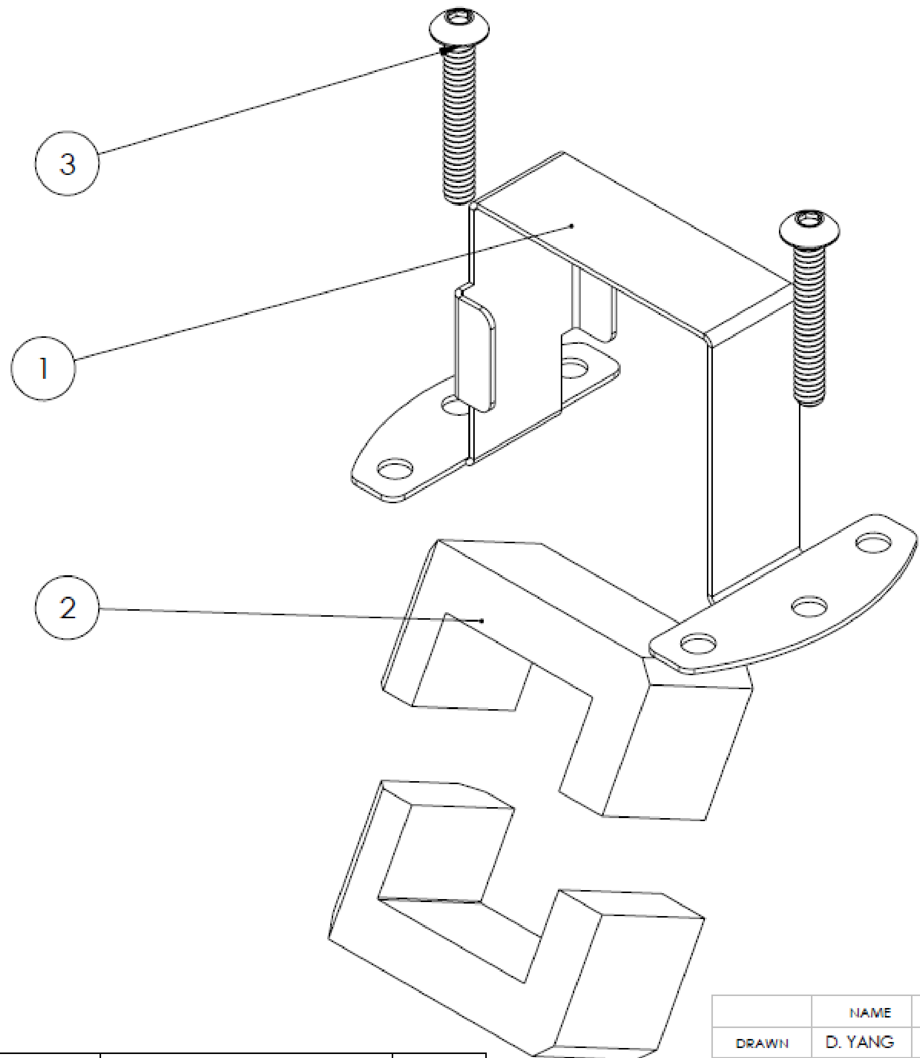


CHKD	J. KIM	6/1/21
DRAWN	D. YANG	6/1/21
COMMENTS:		

MATERIAL
VARIOUS
DO NOT SCALE DRAWING

TITLE:
HINGE ASSEMBLY

SIZE	DWG. NO.	REV
A	112000	B
SCALE: 1:1	WEIGHT: 1LB	SHEET 1 OF 1



NOTE: ONLY 2 SCREWS PICTURED, BUT ALL 6 RECOMMENDED.

#	PART #	DESC	QTY
1	112100	BUSHING CARRIER	1
2	112200	BUSHING HALF	2
3	112300	HINGE SCREW	6

MATERIAL: VARIOUS

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	D. YANG	6/1/21

COMMENTS:

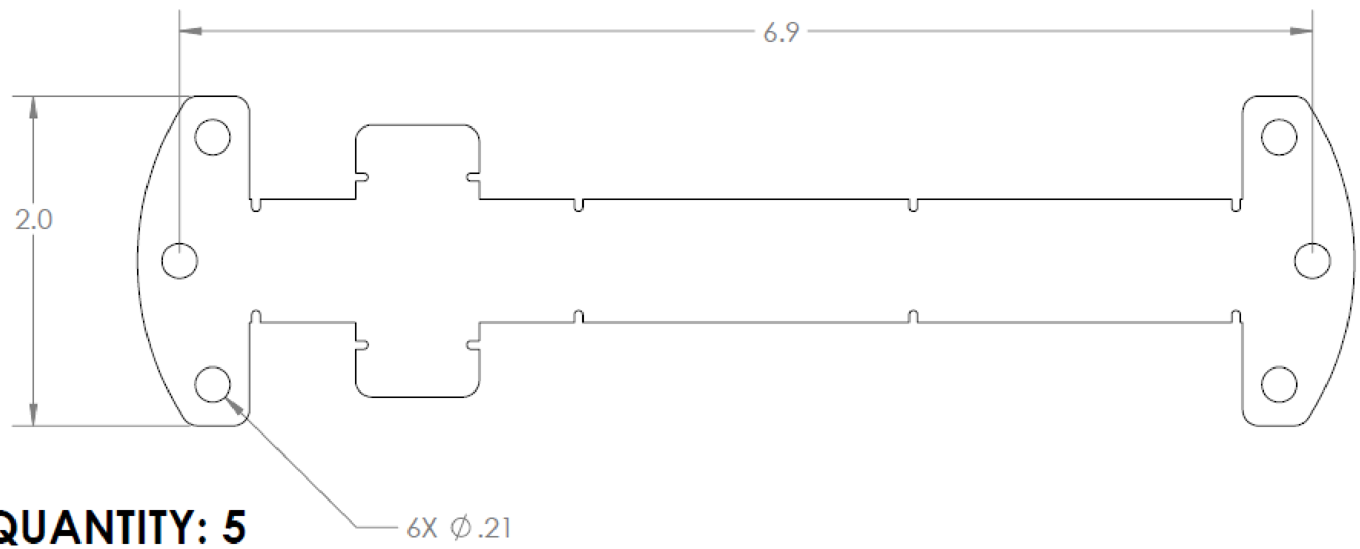
CHKD: J. KIM 6/2/21

TITLE:

HINGE ASS'Y, EXPLODED

SIZE	DWG. NO.	REV
A	112000E	B

SCALE: 1:2 | WEIGHT: 1LB | SHEET 1 OF 1



QUANTITY: 5
(1X SPARE)

DRAWING FOR REFERENCE ONLY

MATERIAL: MILD STEEL

FINISH: RAW WATERJET

DO NOT SCALE DRAWING

COMMENTS:

DRAWN: D. YANG, 5/11/21

TITLE: BUSHING CARRIER

SIZE: A

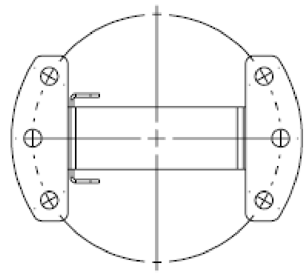
DWG. NO.: 112100

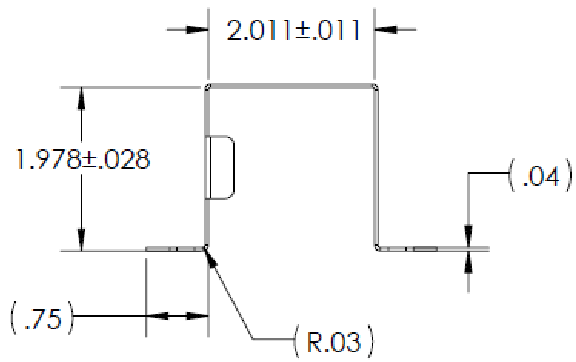
REV: D

SCALE: 1:1

WEIGHT:

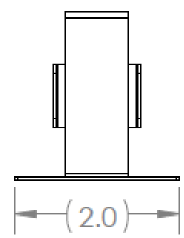
SHEET 1 OF 2



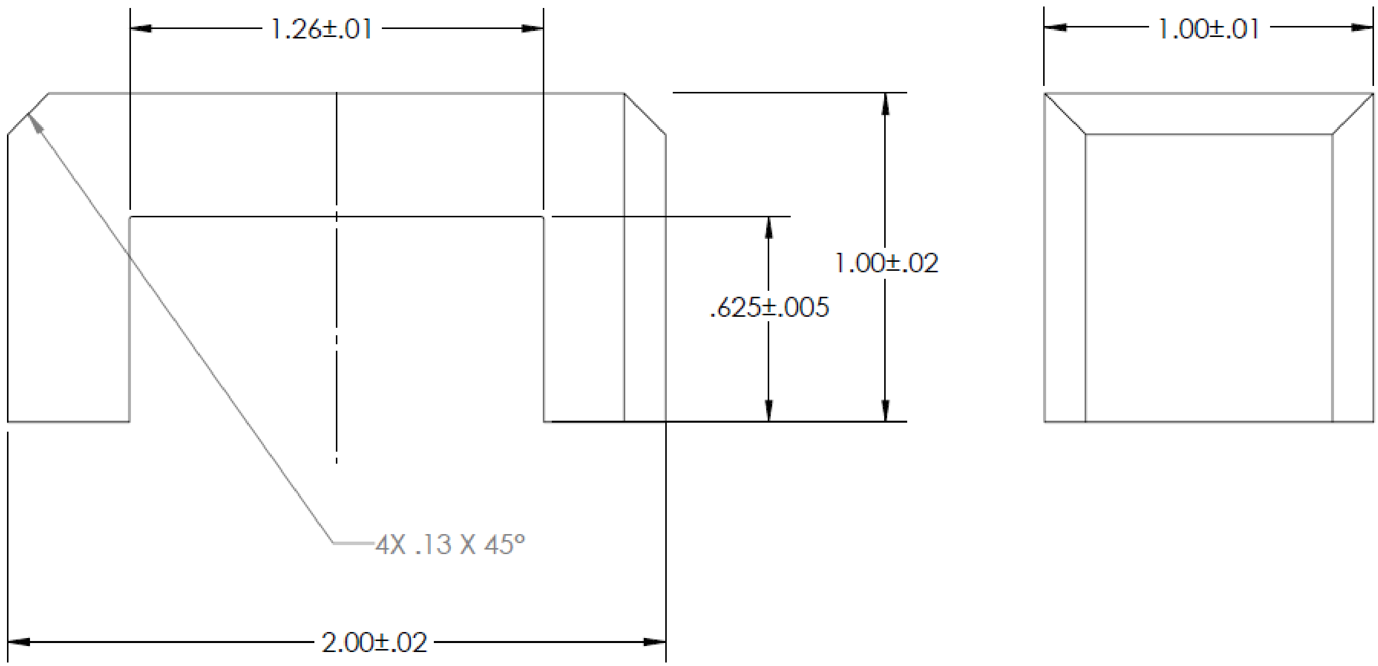


NOTE: ALL BENDS ARE TO BE HAMMERED OVER A RIGHT ANGLE. USE DXF TO WATERJET PARTS.

QTY: 4



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	D. YANG	6/1/21	
	CHECKED	J. KIM	6/1/21	TITLE: BUSHING CARRIER
INTERPRET GEOMETRIC TOLERANCING PER:	COMMENTS:			
MATERIAL				SIZE A
FINISH				DWG. NO. 112100
DO NOT SCALE DRAWING				REV D
				SCALE: 1:2
				WEIGHT:
				SHEET 2 OF 2



MATERIAL
UHMWPE
DO NOT SCALE DRAWING

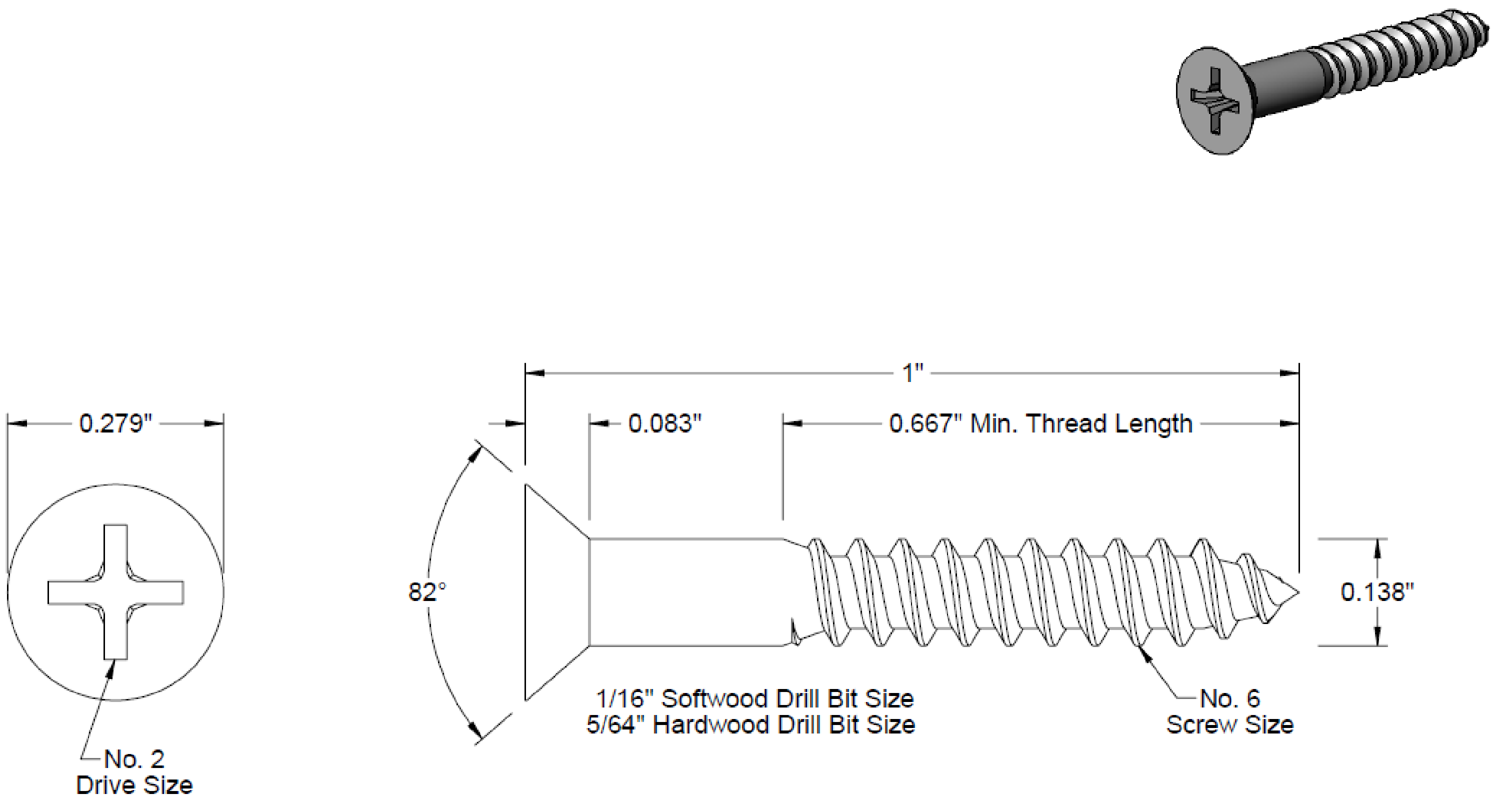
CHKD	J. KIM	2/10/21
DRAWN	D. YANG	2/10/21

COMMENTS:

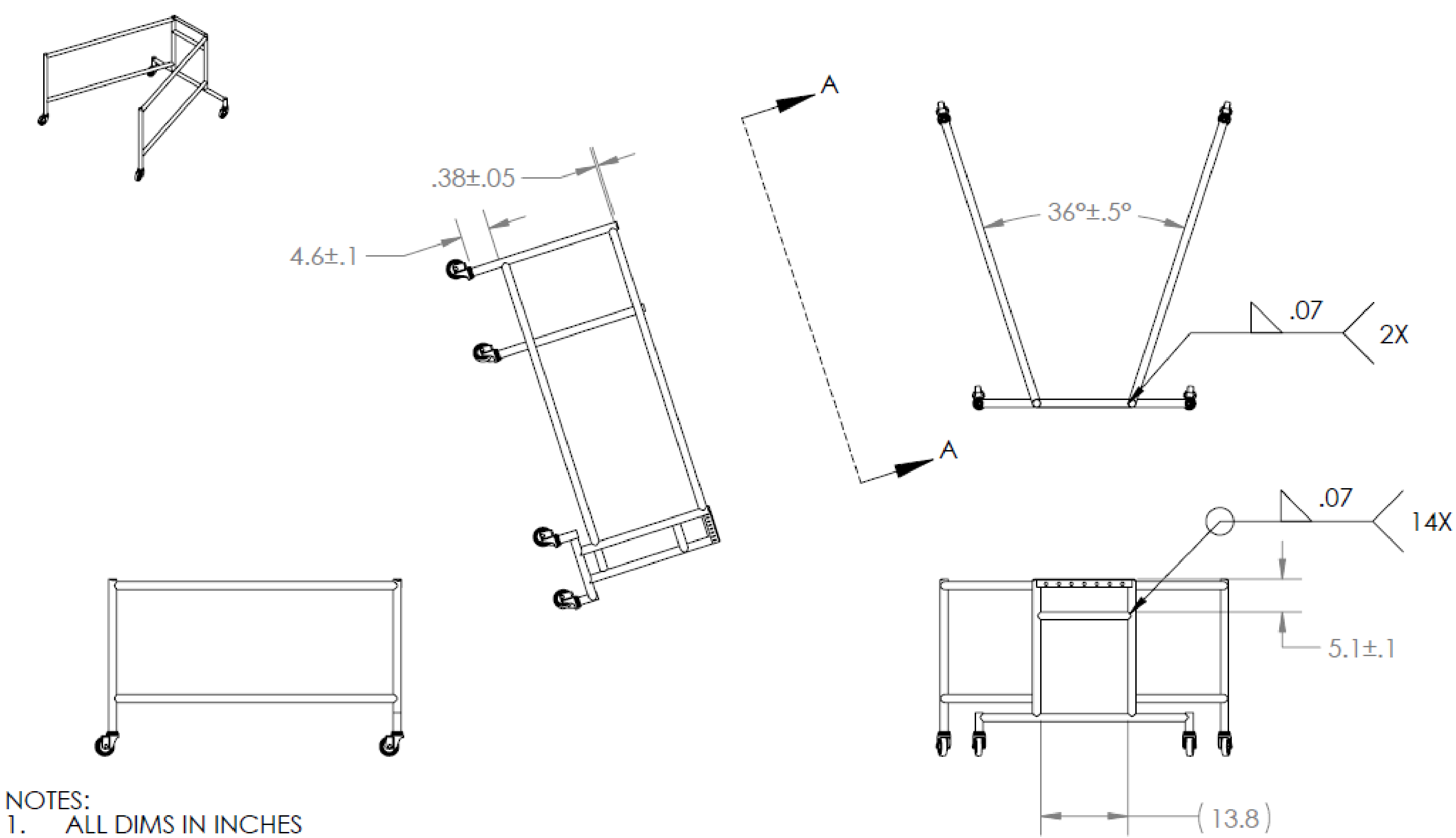
TITLE:
BUSHING HALF

SIZE	DWG. NO.	REV
A	112200	A

SCALE: 2:1 | WEIGHT: <1LB | SHEET 1 OF 1



McMASTER-CARR	PART NUMBER 112300
http://www.mcmaster.com © 2018 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Steel Phillips Flat Head Screw for Wood



NOTES:
1. ALL DIMS IN INCHES
2. 18X FILLET WELDS ALL AROUND TO JOIN TUBES

CHKD	J. KIM	6/2/21
DRAWN	D. YANG	6/1/21

COMMENTS:

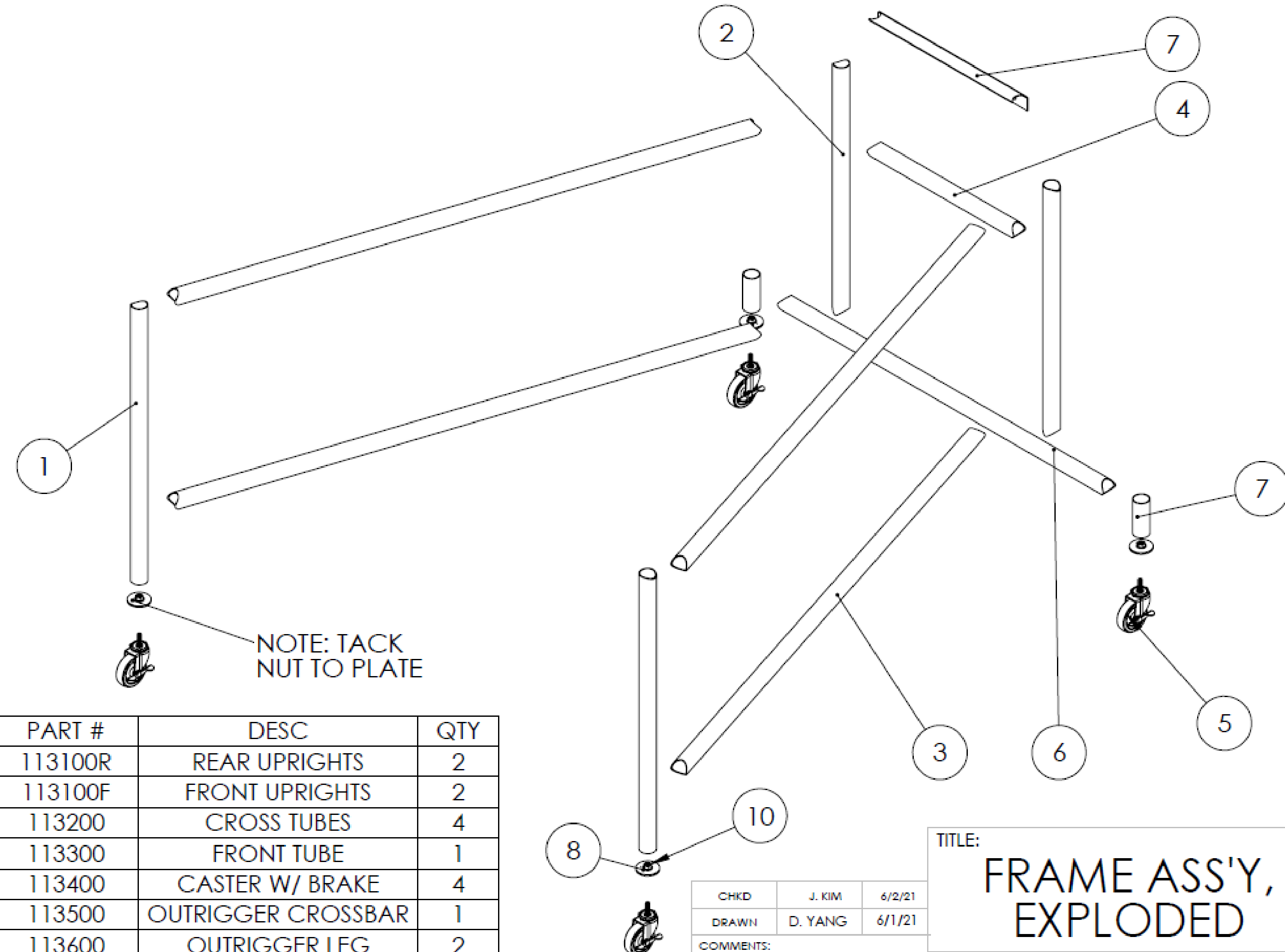
MATERIAL
MILD STEEL

DO NOT SCALE DRAWING

TITLE:
FRAME ASSEMBLY

SIZE	DWG. NO.	REV
A	113000	D

SCALE: 1:24 WEIGHT: 20LB SHEET 1 OF 1



#	PART #	DESC	QTY
1	113100R	REAR UPRIGHTS	2
2	113100F	FRONT UPRIGHTS	2
3	113200	CROSS TUBES	4
4	113300	FRONT TUBE	1
5	113400	CASTER W/ BRAKE	4
6	113500	OUTRIGGER CROSSBAR	1
7	113600	OUTRIGGER LEG	2
8	113800	BUMP STOP	1
9	113900	CASTER PLATE	4
10	113910	CASTER NUT	4

MATERIAL: MILD STEEL

DO NOT SCALE DRAWING

CHKD	J. KIM	6/2/21
DRAWN	D. YANG	6/1/21

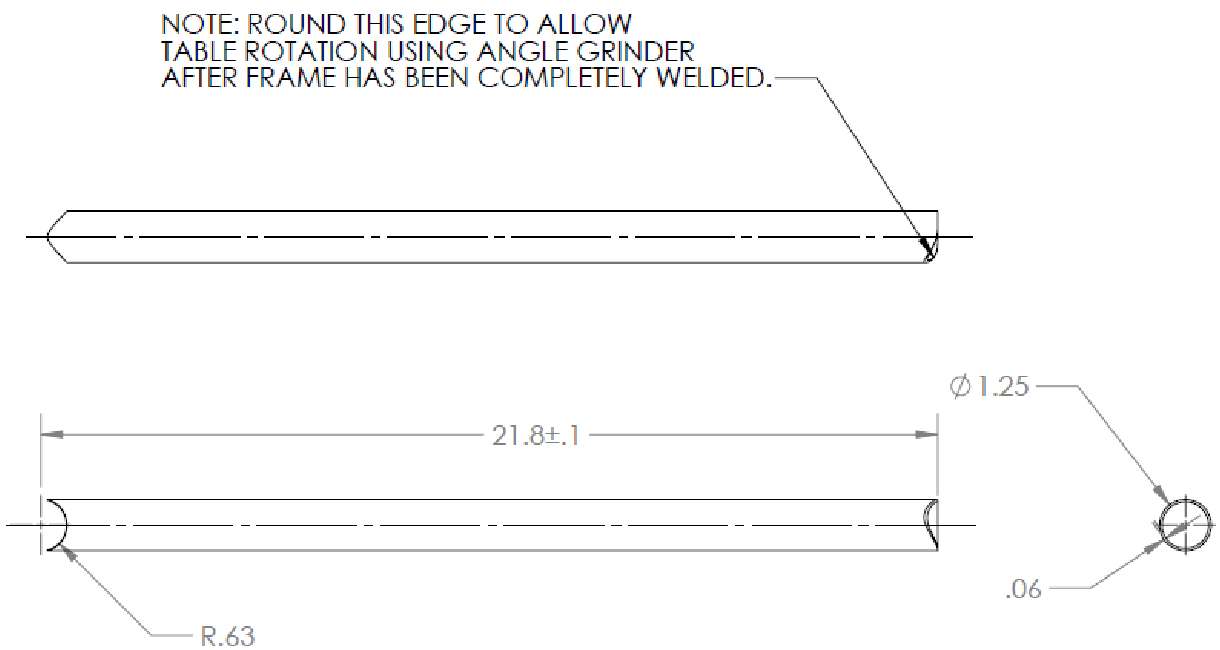
COMMENTS:

TITLE:

FRAME ASS'Y, EXPLODED

SIZE	DWG. NO.	REV
A	113000E	D

SCALE: 1:10 | WEIGHT: 20LB | SHEET 1 OF 1



NOTES:
USE ABRASIVE TUBE NOTCHER IN HANGAR.
CHAMFER ALL NOTCHED EDGES.

CHKD	J. KIM	6/2/21
DRAWN	D. YANG	6/1/21

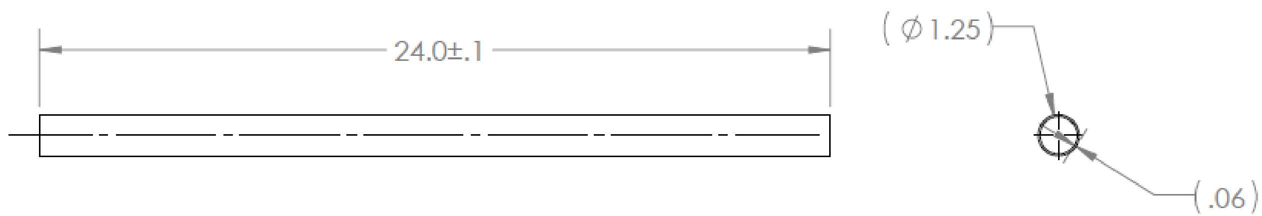
COMMENTS:
ALL DIMS IN INCHES
QTY: 2

MATERIAL
16ga MILD STEEL
DO NOT SCALE DRAWING

TITLE:
F UPRIGHT

SIZE	DWG. NO.	REV
A	113100R	B

SCALE: 1:4	WEIGHT: 2LB	SHEET 1 OF 1



CHKD	J. KIM	6/2/21
DRAWN	D. YANG	6/1/21

COMMENTS:
ALL DIMS IN INCHES
QTY: 2

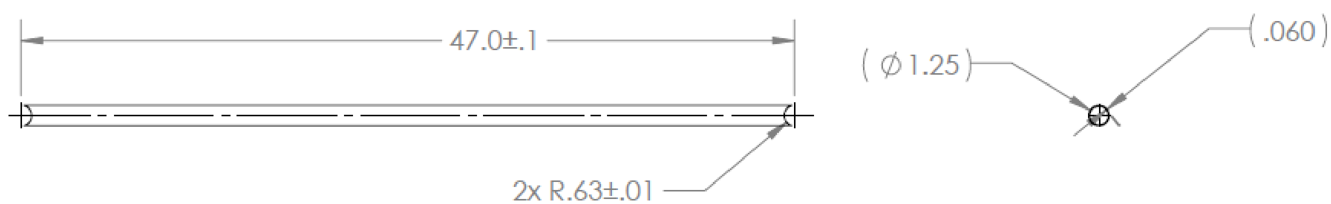
MATERIAL
MILD STEEL

DO NOT SCALE DRAWING

TITLE:
R UPRIGHT

SIZE	DWG. NO.	REV
A	113100R	A

SCALE: 1:5 | WEIGHT: 2LB | SHEET 1 OF 1



NOTES:
USE ABRASIVE TUBE NOTCHER IN HANGAR.
CHAMFER ALL NOTCHED EDGES.

	J. KIM	6/2/21
DRAWN	D. YANG	6/1/21

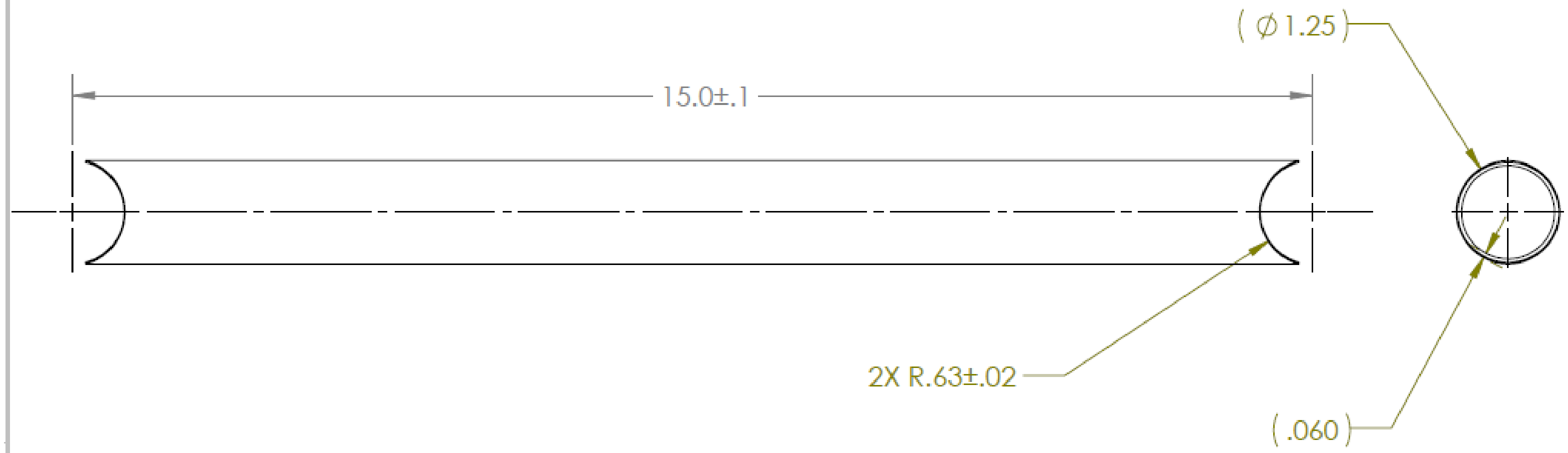
TITLE: CROSS TUBES

COMMENTS:
ALL DIMS IN INCHES
QTY: 4

MATERIAL
16ga MILD STEEL
DO NOT SCALE DRAWING

SIZE A | DWG. NO. 113200 | REV B

SCALE: 1:10 | WEIGHT: 2LB | SHEET 1 OF 1



NOTES:
USE ABRASIVE TUBE NOTCHER IN HANGAR.
CHAMFER ALL NOTCHED EDGES.

CHKD	J. KIM	6/2/21
DRAWN	D. YANG	6/1/21

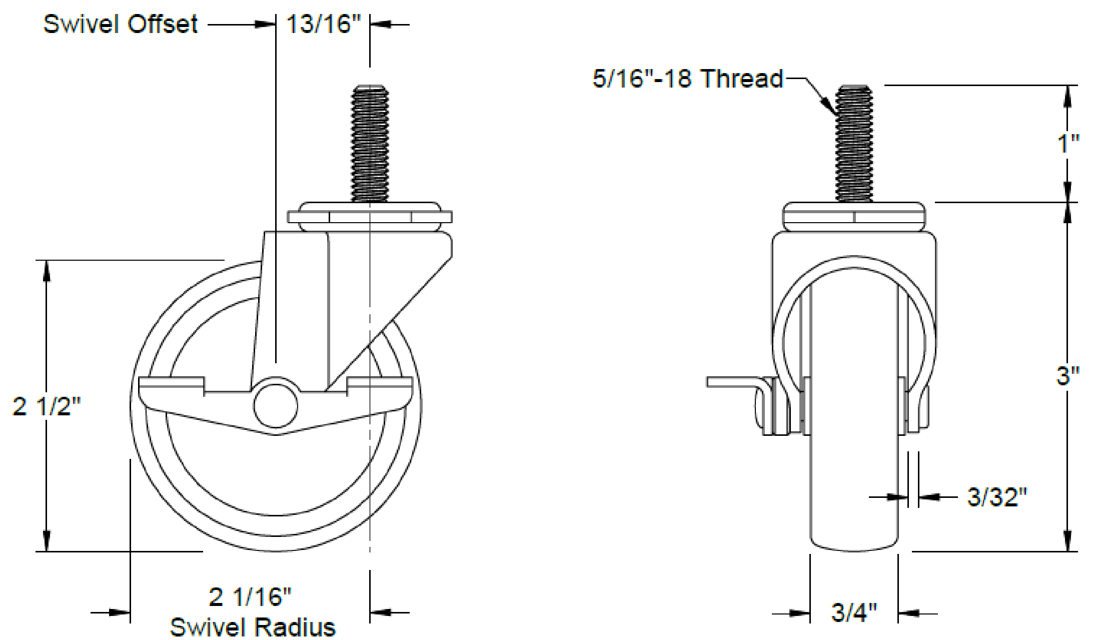
COMMENTS:
ALL DIMS IN INCHES
QTY: 2

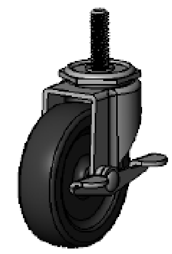
MATERIAL
16ga MILD STEEL
DO NOT SCALE DRAWING

TITLE:
FRONT CROSS TUBE

SIZE	DWG. NO.	REV
A	113300	B

SCALE: 1:2 | WEIGHT: 1LB | SHEET 1 OF 1





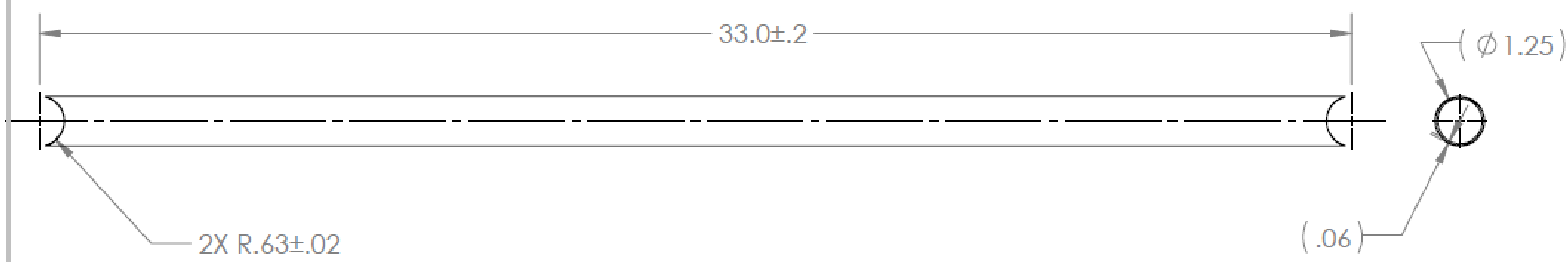
McMASTER-CARR® CAD

http://www.mcmaster.com

Information in this drawing is provided for reference only.

PART NUMBER **113400**

Threaded-Stem
Swivel Caster with Brake



NOTES:
USE ABRASIVE TUBE NOTCHER IN HANGAR.
CHAMFER ALL NOTCHED EDGES.

CHKD	J. KIM	6/2/21
DRAWN	D. YANG	6/1/21

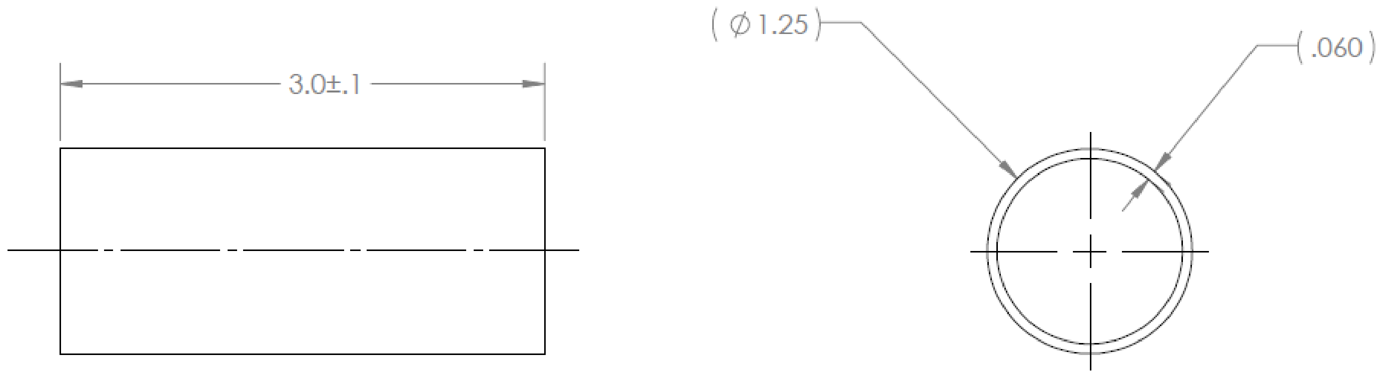
COMMENTS:
ALL DIMS IN INCHES
QTY: 2

MATERIAL
16ga MILD STEEL
DO NOT SCALE DRAWING

TITLE:
OUTRIGGER ARM

SIZE	DWG. NO.	REV
A	113500	B

SCALE: 1:2 | WEIGHT: <1LB | SHEET 1 OF 1



TITLE:

OUTRIGGER LEG

	J. KIM	6/2/21
DRAWN	D. YANG	6/1/21

COMMENTS:

ALL DIMS IN INCHES
QTY: 2

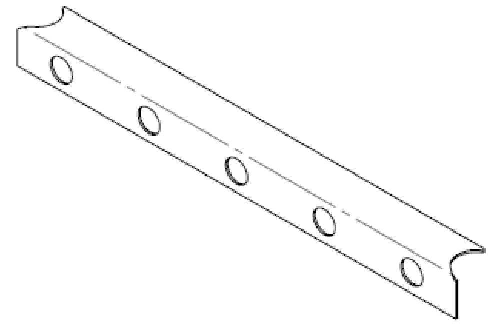
MATERIAL
16ga MILD STEEL

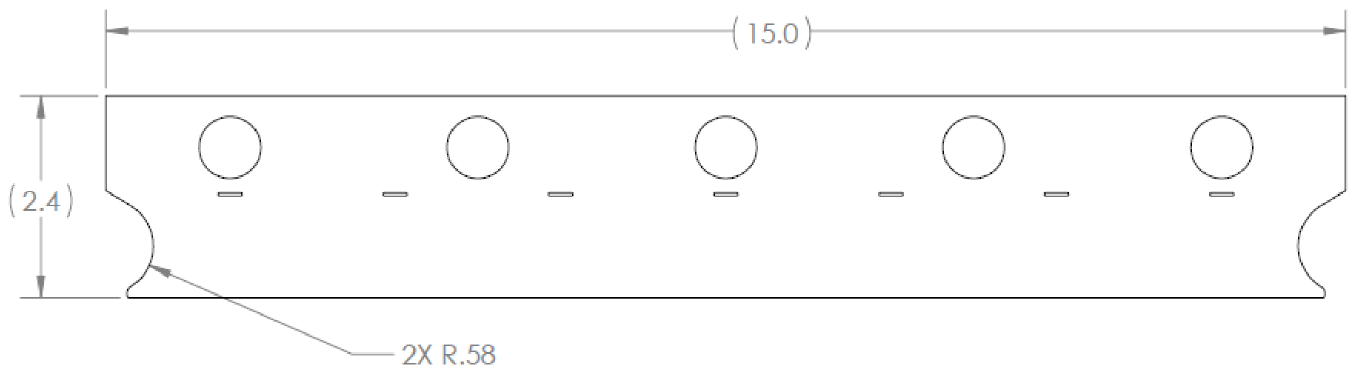
DO NOT SCALE DRAWING

SIZE	DWG. NO.	REV
A	113600	B

SCALE: 1:1 | WEIGHT: <1LB | SHEET 1 OF 1

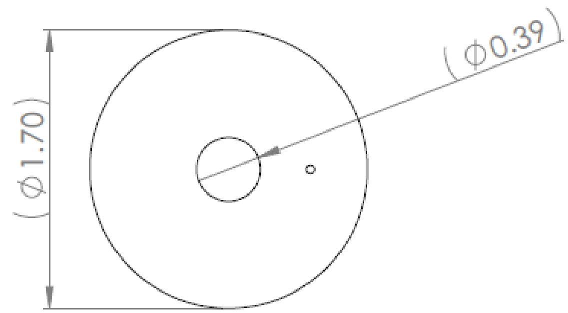
NOTES:
ONE 90° BEND ALONG DASHED CUTOUTS.
PART IS SLIGHTLY OVERSIZED TO ALLOW FOR WELDING WARPAGE.
GRIND PART TO FIT FRAME BEFORE WELDING IN.





		NAME	DATE	
WATERJET PART.	DRAWN	D. YANG	6/1/21	
QTY: 1	CHECKED	J. KIM	6/2/21	TITLE: BUMP STOP
USE 16GA STEEL.				
	COMMENTS:			SIZE: A
FINISH				DWG. NO. 113800
DO NOT SCALE DRAWING				REV C
				SCALE: 1:2
				WEIGHT: 1LB
				SHEET 1 OF 1

QTY: 5 (1X SPARE)
USE 1/8" STEEL



DRAWING FOR REFERENCE ONLY

MATERIAL
MILD STEEL

FINISH
RAW WATERJET

DO NOT SCALE DRAWING

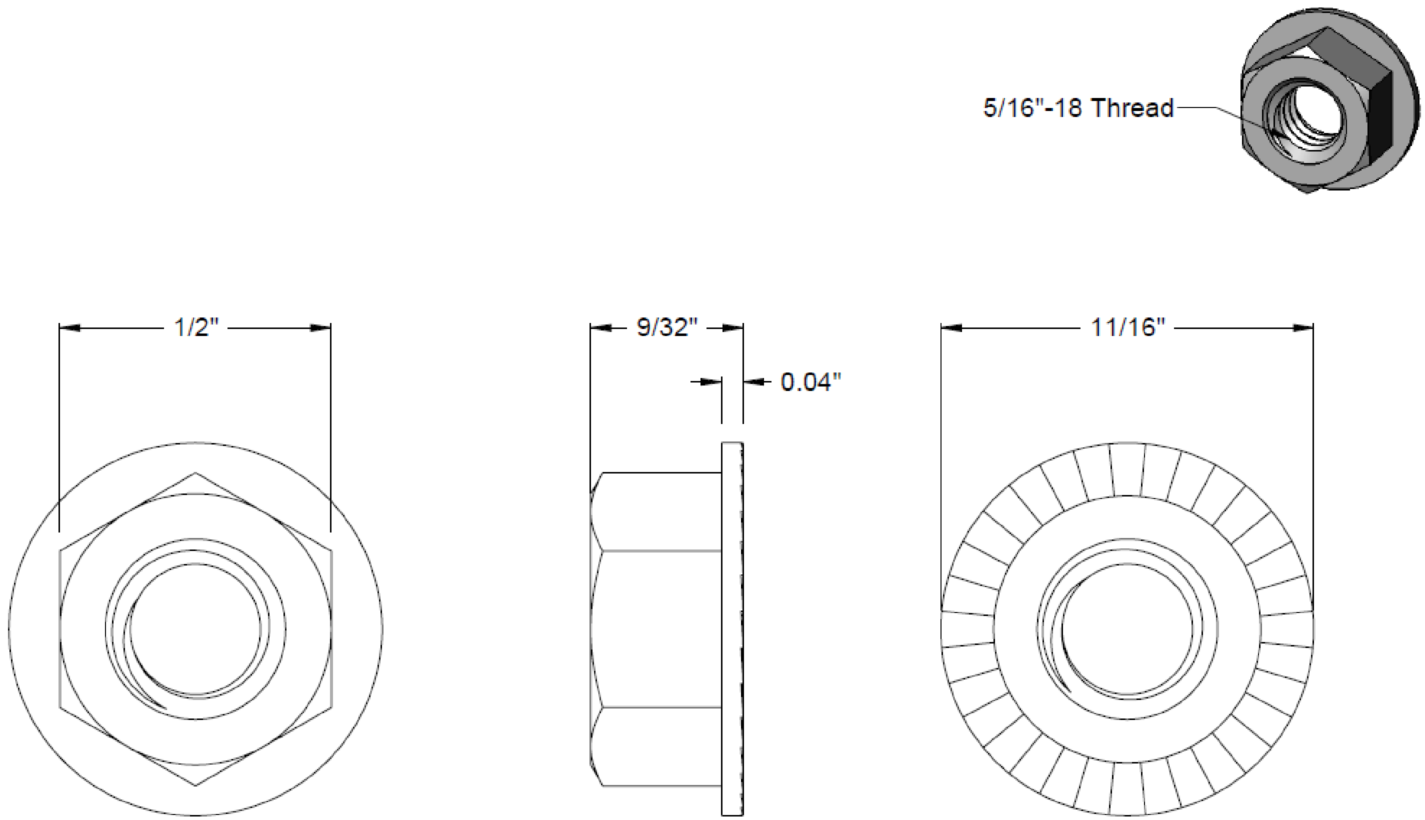
COMMENTS:

DRAWN D. YANG 6/1/21
CHKD J. KIM 6/2/21

TITLE:
CASTER MOUNT

SIZE: A
DWG. NO. 113900
REV: A

SCALE: 1:1
WEIGHT: 0.2 LB
SHEET 1 OF 1



McMASTER-CARR. CAD

PART NUMBER **113910**

http://www.mcmaster.com

Serrated-Flange Locknut

Appendix Q: Manufacturing Process

Appendix Q: Manufacturing Process

F31 Manufacturing Plan							
Parts		**Procuring**				**Manufacturing**	
Assembly	**Subassembly**	**Method***	**Material**	**Location**	**URL**	**Equipment & Operation****	**Assembly notes**
Tabletop	Tabletop	b	(choose type of table top material) MDF composite	Ikea/furniture website	https://www.ikea.com/us/en/p/linnmon-tabletop-white-20251139/	Drill press	Test pull-out load to figure out how to fix the hinge to the table. Potted inserts?
	Tongue and Groove	c	clear pine	Home Depot	https://www.homedepot.com/p/1-in-x-3-in-x-6-ft-Select-Pine-Board-921824/202535801	Table router	n/a
	Compression Latch	a	Steel	Amazon	https://www.amazon.com/dp/B07RH71J2R/ref=cm_sw_r_sms_apip_UHrcWDhHAAt85	n/a	use wood anchors with latches - do not thread directly into table.
	Wood Anchors	a	Metal	Home Depot	https://www.homedepot.com/p/E-Z-Ancor-Stud-Solver-40-lbs-6-x-1-1-4-in-Hollow-Door-and-Drywall-Anchors-2-Pack-25425/310450446	Power Drill	Generally require pilot holes for precision. If installing into table siding, clear plastic siding with 3/8" drill bit.
Hinges	Bushing Half	c	UHMWPE	Interstateplastics Online Metals	https://www.interstateplastics.com/UHMW?&searchtext=uhmw&kw=uhmw&gclid=CjwKCAiA_9r_BRBZEiwAHZ_v11XlJIzQnWk_etJnRc2IiPJJ2RFyp2a2AjRySgKPEsFWeSZOSUtcjRoCXHgQAvD_BwE https://www.onlinemetals.com/en/buy/alloy-steel-round-tube	Band saw, mill/lathe or table router	cut stock to size, machine appropriate ID/OD.
	Bushing Carrier	c	Sheet Steel	Online Metals	https://www.amazon.com/Mounted-Pillow-Block-Bearings/b?ie=UTF8&node=220003011	waterjet, vise, ball-peen hammer	hammering into shape requires some creative fixturing.

					https://www.onlinemetals.com/en/buy/hot-roll-steel/0-06-mild-steel-sheet-a569-astm-a1011-hot-rolled/pid/9900		
	Hinge Screw	a	n/a	Home Depot	https://www.homedepot.com/p/Everbilt-6-x-1-in-Zinc-Plated-Phillips-Flat-Head-Wood-Screw-100-Pack-801772/204275493	n/a	Thread into wood anchors; do not thread directly into fiberboard.
Frame	Rear Uprights	c	Steel round tubes	Online Metals	https://www.onlinemetals.com/en/buy/alloy-steel-round-tube	Band saw, tube notcher, weld	contract welding with shop techs, or reach out to another fabricator
	Front Uprights	c	Steel round tubes	Online Metals	https://www.onlinemetals.com/en/buy/alloy-steel-round-tube	SAME	SAME
	Cross Tubes	c	Steel round tubes	Online Metals	https://www.onlinemetals.com/en/buy/alloy-steel-round-tube	SAME	SAME
	Front Cross Tube	c	Steel round tubes	Online Metals	https://www.onlinemetals.com/en/buy/alloy-steel-round-tube	SAME	SAME
	Outrigger Cross Bar	c	Steel round tubes	Online Metals	https://www.onlinemetals.com/en/buy/alloy-steel-round-tube	SAME	SAME
	Outrigger Leg	c	Steel round tubes	Online Metals	https://www.onlinemetals.com/en/buy/alloy-steel-round-tube	SAME	SAME
	Paint	a	Spray paint	Home Depot	https://www.homedepot.com/p/Rust-Oleum-Stops-Rust-12-oz-Protective-Enamel-Gloss-Smoke-Gray-Spray-Paint-7786830/100198382	n/a	n/a
	Caster Wheels w/ brakes	a	n/a	McMaster-Carr	https://thecasterguy.com/product/3-polyurethane-expandable-caster-w-brake-53865/	n/a	n/a
	Bump Stop	c	Steel Sheets	Online Metals	https://www.onlinemetals.com/en/buy/carbon-steel/0-06-carbon-	Waterjet, sheet metal brake	waterjet and bend into shape

					steel-sheet-a569-astm-a1011-hot-rolled/pid/9900		
	Caster Plate	c	Steel Sheets	Online Metals	https://www.onlinemetals.com/en/buy/carbon-steel/0-125-carbon-steel-sheet-a366-1008-cold-roll/pid/13973	Waterjet	n/a
	Caster Nut	a	Steel	McMaster-Carr	https://www.mcmaster.com/91762A150/	n/a	weld to caster plate

* (a) Purchased, (b) modified from purchased, and (c) made from raw materials

** applicable if the procuring method is either (b) or (c)

The manufacturing plan contains detailed instructions for the manufacture and assembly of the table. While the detail drawings can be found in **Error! Reference source not found. Error! Reference source not found.**, manufacturing and assembly instructions are provided below for each custom built/modified component.

Tongue and Groove (111200 – 111300)

1. Cut to length specified in drawings.
2. Using a table router, cut the required profiles.

Bushing Half (112200)

1. Cut the appropriate stock size from a large sheet of UHMWPE.
2. Using a mill, cut the stock to the exact size then slot the part to the required dimension.
3. Use a belt sander to make the chamfers.

Bushing Carrier (112100)

1. After waterjetting the parts, use a ball-peen hammer and vise to bend the carriers into shape. Note the flaps that constrain the bushings' axial movement should be hammered out last around a 1" wide steel block, such as a toe clamp or other appropriate piece.

Frame Tubes (113100R, 11300F, 113200, 113300, 113500, 113600)

1. Use an abrasive cut-off saw to cut each tube to the length specified in the respective drawing.
2. For tubes that require notching, use a tube notcher to make the notches, paying attention to the clocking of tubes that are notched on both ends.

Bump Stop (113800)

1. After waterjetting the part, use a metal brake to bend the part into shape.

Caster Plate (113900)

1. After waterjetting the part, weld the caster nut (113910) onto the caster plate using a caster's shaft to make sure that the nut is centered on the plate.
2. After welding, chase the threads with an appropriate tap.

The following section contains detailed assembly instructions for the subassemblies.

Tabletop Assembly (111000)

1. Epoxy the tongue and groove onto each respective tabletop.
2. Further assembly will be completed in the final steps.

Frame Assembly (113000)

1. Prep the weld areas of each tube with a wire wheel and acetone.

2. Lay out the tubes that make the front of the table (Front Cross Tube, Front Upright, Outrigger Cross Bar, Outrigger Leg) on a large welding table to the dimensions specified in the drawing.
3. Tack each joint, then weld all around.
4. Lay out the tubes that make each side (2x Cross Tubes, Rear Upright). Tack, then full weld.
5. Repeat step 4 to make the second side.
6. Use the welding jig and a measuring tape to properly align each part.

Figure Q 1: The welding jig closes the open part of the trapezoid base.

7. Tack each joint, then weld all around the appropriate joints.
8. Weld in the caster plates to the feet of the table.
9. Screw the casters into the mounts and hand tighten.

Final Assembly (111000, 112000, 113000)

1. Fit the tongue and groove tabletops together, forming a large square. Flip upside down.
2. Fit hinge assemblies were fitted to the tabletop as shown in Figure Q 2. After centering the frame and positioning the hinges, mark and drill ¼” pilot holes for each of the hinge assemblies as shown in Figure Q 3.

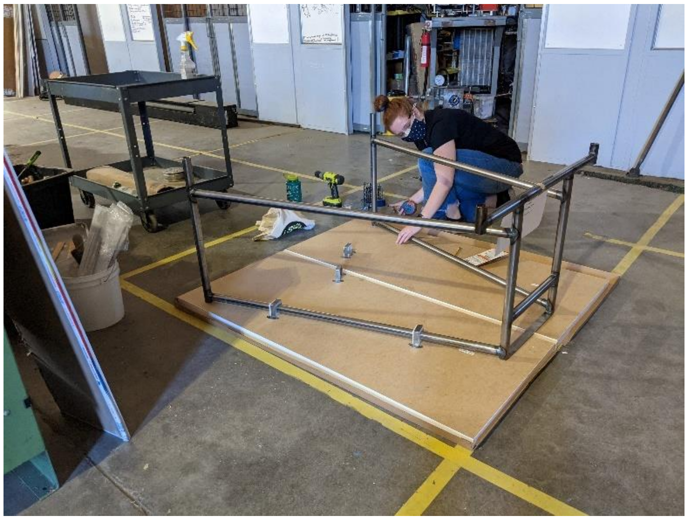


Figure Q 2: Hinge to tabletop assembly demonstration.

Figure Q 3: Locating the holes for wood anchors.

Figure Q 4: Assembled transportable.

3. Position the latch, then used as a jig to locate pilot holes for the anchors as shown in Figure Q 5.
4. The pilot holes should be drilled with a ¼” bit, then the plastic around the pilot hole should be cleared with a 3/8” drill to prevent deforming the surface when the anchor is installed.
5. Attach the latches to the anchor points.

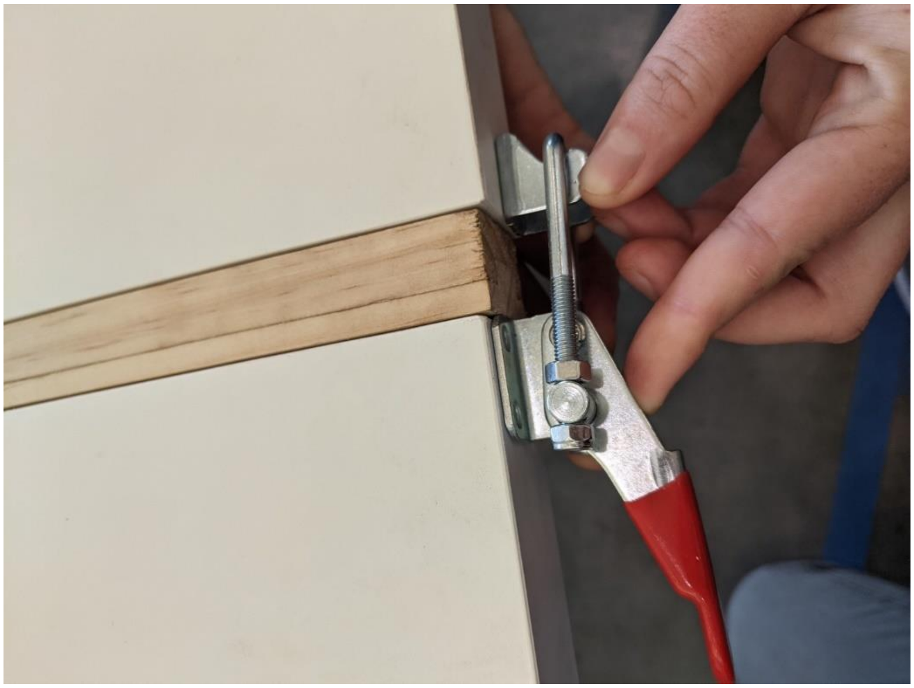


Figure Q 5: Compression latch install demonstration.

Appendix R: Design Verification Plan and Results

Appendix R: Design Verification Plan and Results

DVP&R - Design Verification Plan (& Report)

Project:	F31 Design Collaborative Space		Sponsor:	Dr. Peter Schuster						Edit Date:	4/22/2021
TEST PLAN										**TEST RESULTS**	
Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Responsibility	TIMING Start date	TIMING Finish date	Numerical Results	Notes on Testing
1	8	Drop weight attached to Table top + hardware combo #1 (Screw only)	P/NP* Ranks	Fastener remains installed / tabletop does not rupture	1. LINNIMON IKEA table top 2. 4 X ADILS Ikea table leg 3. Fabric Cord 4. 10lb weight	1. Everbilt Screw eye	Jung	2/5/2021	2/11/2021	1. Hand Pull (Pass) 2. 10lb Drop @ 3ft (Pass) 3. Destructive Test (3)	
2	8	Drop weight attached to Table top + hardware combo #2 (Screw + EZ Ancor hollow door & drywall anchor)	P/NP* Ranks	Fastener remains installed / tabletop does not rupture	1. LINNIMON IKEA table top 2. 4 X ADILS Ikea table leg 3. Fabric Cord 4. 10lb weight	1. Everbilt Screw eye 2. EZ Ancor hollow door & drywall anchor	Jung	2/5/2021	2/11/2021	1. Hand Pull (Pass) 2. 10lb Drop @ 3ft (Pass) 3. Destructive Test (2)	
3	8	Drop weight attached to Table top + hardware combo #3 (Screw + Everbilt zinc tee nuts)	P/NP* Ranks	Fastener remains installed / tabletop does not rupture	1. LINNIMON IKEA table top 2. 4 X ADILS Ikea table leg 3. Fabric Cord 4. 10lb weight	1. Everbilt Screw eye 2. Everbilt zinc tee nuts	Jung	2/5/2021	2/11/2021	1. Hand Pull (NP) 2. 10lb Drop @ 3ft (Pass) 3. Destructive Test (5)	
4	8	Drop weight attached to Table top + hardware combo #4 (Screw + EZ Ancor hollow door & drywall anchor+ adhesive)	P/NP* Ranks	Fastener remains installed / tabletop does not rupture	1. LINNIMON IKEA table top 2. 4 X ADILS Ikea table leg 3. Fabric Cord 4. 10lb weight	1. Everbilt Screw eye 2. EZ Ancor hollow door & drywall anchor 3. Gorilla super glue adhesive	Jung	2/5/2021	2/11/2021	1. Hand Pull (Pass) 2. 10lb Drop @ 3ft (Pass) 3. Destructive Test (1)	Hardware combo #4 performed the best among the total combinations, and is chosen to be used for the final design.
5	8	Drop weight attached to Table top + hardware combo #5 (Screw + Everbilt zinc tee nuts + adhesive)	P/NP* Ranks	Fastener remains installed / tabletop does not rupture	1. LINNIMON IKEA table top 2. 4 X ADILS Ikea table leg 3. Fabric Cord 4. 10lb weight	1. Everbilt Screw eye 2. Everbilt zinc tee nuts 3. Gorilla super glue adhesive	Jung	2/5/2021	2/11/2021	1. Hand Pull (NP) 2. 10lb Drop @ 3ft (NP) 3. Destructive Test (4)	
6	1	In CAD and in real life, take two models and nest them together.	1. 'Maximum length of one table' ** 2. 'Additional length added by nesting table' **	< 16% difference of 'maximum length of one table' and ' and 'additional length added by nesting table' dimensions.	1. Tape measure 2. Leveled floor with at least 20' by 20' dimension.	1. 2x table Verfication Prototype	David	5/11/2021	5/22/2021	Tables stack with 89% efficiency, which means a 11% difference.	
7	2,3	Deploy and stow table. Time each articulation.	Deploy time, Fold time	Deployment time < 30sec, stow time < 45sec.	1. Stop Watch 2. Leveled floor with at least 20' by 20' dimension. 3. 7x testing personnel	1. Verfication Prototype	Ellie	5/4/2021	5/22/2021	Stowed in 33 sec. (P) deployed in 34 sec (NP)	deploy and stow times were decided arbitrarily; we believe +5 sec is usable

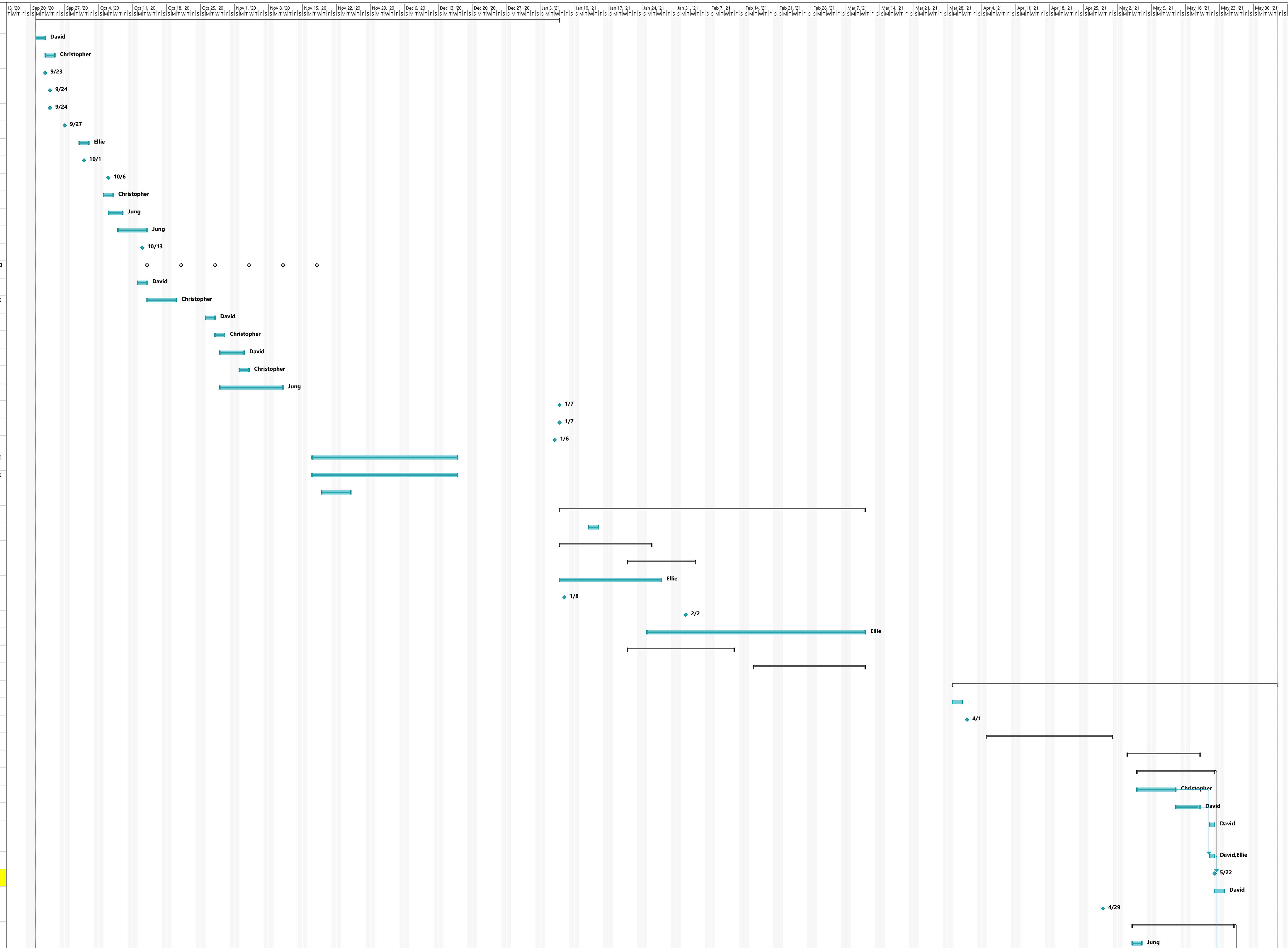
Appendix R: Design Verification Plan and Results

8	6	Place 125lbs. of weight at forward corner of table	P/NP*	Table does not tip over or permanantly deform	1. 12" Disk 2. Leveled floor with at least 15' by 15' dimension. 3. 12 x 10 lbs. Tarp Sandbags	1. Verfication Prototype	David	5/4/2021	5/22/2021	125 lb. applied at forward corner (P)	5 degrees of deflection noted.
9	7	Place 200lbs. of weight at rear middle of table	P/NP* Unload Height, Loaded Height	Table does not permanantly deform Deflection < 1/2 inch to pass	1. 12" Disk 2. Leveled floor with at least 15' by 15' dimension. 3. 20 x 10 lbs. Tarp Sandbags	1. Verfication Prototype	Ellie	5/4/2021	5/22/2021	101.8 lb applied before cracking noises heard (NP)	Only applied 102 lb before team noted cracking noises and concerning deflection. **Consider redesigning table joining system from the ground up.**
10	8	Drop table from 2.4 inches above the ground	P/NP*	Table shows no visble damage	1. 2x testing personnel 2. Leveled floor with at least 15' by 15' dimension. 3. Tape measure	1. Verfication Prototype	Ellie	5/4/2021	5/22/2021	dropped with no visible damage (P).	
11	9	Holding other table legs static, apply 100lbs side load to each table leg when deployed	P/NP*	Table shows no visble damage	1. 2x testing personnel 2. Leveled floor with at least 15' by 15' dimension. 3. 6' long polypropylene rope 4. Hanging scale (digital or analog)	1. Verfication Prototype	David	5/11/2021	5/12/2021	(P) permanent deformation visible when loaded in folded configuration but passed when deployed. Frame is slightly bent but still usable.	applied an overload of ~140 lb due to limited resources (no strain gauge available).
12	3,4	Long-term Usage: study at table for a week	Survey Feedbacks	No significant negative feedback	small group of participants, study space, work materials	1. Verfication Prototype	Ellie	5/18/2021	5/19/2021		Decided to address the feedbacks in the recommendation section of the report; Test #12 will no longer be part of verification.
13	2,3	Bushing Carrier manufacutring tolerance test ***	Arbitrary width measurements of the bushing carrier samples (9X)	Establish key dimensions for bushing carrier at 95% confidence.	1. Caliper	1. 9X manufacutred bushing carrier	David	5/11/2021	5/27/2021	Recommended dimensions are A = 2.011 ± .011 in. and B = 1.978 ± .028 in.	See DVPR #13 procedure for more information.

* P/NP measurement criteria will be a binary data of passing (P) and not passing (NP) the test
** See dimension description in DVPR #6 test procedure
*** Test involving uncertainty analysis

Appendix S: Gantt Chart

ID	Task Name	Duration	Start	Finish
1	**Fall Quarter**	**78 days**	**Mon 9/21/20**	**Thu 1/7/21**
2	Technical Research	2 days	Mon 9/21/20	Tue 9/22/20
3	Stakeholder Research	2 days	Wed 9/23/20	Thu 9/24/20
4	Sponsor introductory email	0 days	Wed 9/23/20	Wed 9/23/20
5	Team Information Sheet	0 days	Thu 9/24/20	Thu 9/24/20
6	Team Design Research Plan	0 days	Thu 9/24/20	Thu 9/24/20
7	Team Date	0 days	Sun 9/27/20	Sun 9/27/20
8	Problem Statement & Stakeholder Needs	2 days	Wed 9/30/20	Thu 10/1/20
9	Team Contract	0 days	Thu 10/1/20	Thu 10/1/20
10	Problem Definition Submission	0 days	Tue 10/6/20	Tue 10/6/20
11	QFD & Specification Table	2 days	Mon 10/5/20	Tue 10/6/20
12	Scope of Work Draft	3 days	Tue 10/6/20	Thu 10/8/20
13	Scope of Work Revision	4 days	Thu 10/8/20	Tue 10/13/20
14	Scope of Work Final	0 days	Tue 10/13/20	Tue 10/13/20
15	**Recurring Sponsor Meeting**	**25 days**	**Wed 10/14/20**	**Wed 11/18/20**
22	Functional Decomposition / Ideation	2 days	Mon 10/12/20	Tue 10/13/20
23	Building Ideation Models	4 days	Wed 10/14/20	Mon 10/19/20
24	Concept Selection	2 days	Mon 10/26/20	Tue 10/27/20
25	Preliminary Analysis	2 days	Wed 10/28/20	Thu 10/29/20
26	Concept CAD	3 days	Thu 10/29/20	Mon 11/2/20
27	Building Concept Prototype	2 days	Mon 11/2/20	Tue 11/3/20
28	PDR report	9 days	Thu 10/29/20	Tue 11/10/20
29	PDR presentation in Lab	0 days	Thu 1/7/21	Thu 1/7/21
30	PDR report Final	0 days	Thu 1/7/21	Thu 1/7/21
31	PDR presentation to Sponser	0 days	Wed 1/6/21	Wed 1/6/21
32	Safety / FMEA	22 days	Tue 11/17/20	Wed 12/16/20
33	DFMA	22 days	Tue 11/17/20	Wed 12/16/20
34	Design Analysis / Winter Plan	4 days	Thu 11/19/20	Tue 11/24/20
35	**Winter Quarter**	**45 days**	**Thu 1/7/21**	**Thu 3/11/21**
36	Watch Interim Design Reviews	2 days	Wed 1/13/21	Thu 1/14/21
37	**Analysis**	**13 days**	**Thu 1/7/21**	**Mon 1/25/21**
46	**Structural Prototypes (SP)**	**10 days**	**Thu 1/21/21**	**Wed 2/3/21**
53	Manufacturing Plan / DVP / Drawings	15 days	Thu 1/7/21	Wed 1/27/21
54	Mfg. Plan Draft	0 days	Fri 1/8/21	Fri 1/8/21
55	Yellow Tag Test	0 days	Tue 2/2/21	Tue 2/2/21
56	Drawing & Manufacturing Plan Review	33 days	Mon 1/25/21	Wed 3/10/21
57	**Critical Design Review (CDR)**	**16 days**	**Thu 1/21/21**	**Fri 2/12/21**
62	**Post CDR**	**17 days**	**Tue 2/16/21**	**Thu 3/11/21**
73	**Spring Quarter**	**49 days?**	**Mon 3/29/21**	**Thu 6/3/21**
74	Experimental Design	2 days	Mon 3/29/21	Tue 3/30/21
75	Test Procedures	0 days	Thu 4/1/21	Thu 4/1/21
76	**VP Mfg.**	**20 days**	**Mon 4/5/21**	**Fri 4/30/21**
95	**Design Revisions**	**11 days**	**Tue 5/4/21**	**Tue 5/18/21**
119	**VP2 Assembly**	**12 days**	**Thu 5/6/21**	**Fri 5/21/21**
120	Order/Receive Casters	6 days	Thu 5/6/21	Thu 5/13/21
121	Weld VP2 Table Frame	3 days	Fri 5/14/21	Tue 5/18/21
122	Make Longer Bump Stop Mounting Plate	1 day	Fri 5/21/21	Fri 5/21/21
123	VP2 Assembly	1 day	Fri 5/21/21	Fri 5/21/21
124	VP2 Assembly Complete	0 days	Sat 5/22/21	Sat 5/22/21
125	VP Paint	2 days	Sat 5/22/21	Sun 5/23/21
126	Senior Exam	0 days	Thu 4/29/21	Thu 4/29/21
127	**DVP Testing**	**15 days**	**Wed 5/5/21**	**Tue 5/25/21**
128	DVP #1	2 days	Wed 5/5/21	Thu 5/6/21



Project: F31 Gantt Chart(new)
Date: Fri 6/4/21

Task | Split | Milestone | Summary | Project Summary | Inactive Task | Inactive Milestone | Inactive Summary | Manual Task | Duration-only | Manual Summary Rollup | Manual Summary | Start-only | Finish-only | External Tasks | External Milestone | Deadline | Progress | Manual Progress

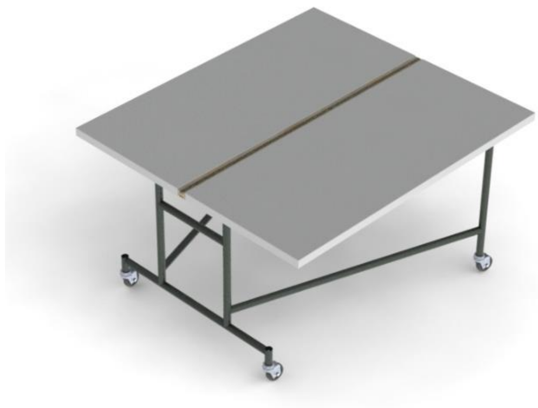
ID		Task Mode	Task Name	Duration	Start	Finish
129			DVP #2	2 days	Wed 5/5/21	Thu 5/6/21
130			DVP #3	2 days	Wed 5/5/21	Thu 5/6/21
131			DVP #4	2 days	Wed 5/5/21	Thu 5/6/21
132			DVP #5	2 days	Wed 5/5/21	Thu 5/6/21
133			DVP #11 - Leg Side Load	1 day	Fri 5/7/21	Fri 5/7/21
134			DVP #6 - Stacking Eff.	1 day	Sat 5/22/21	Sat 5/22/21
135			DVP #7 - Deploy/Stow	1 day	Sat 5/22/21	Sat 5/22/21
136			DVP #8 - Corner Weight	1 day	Sat 5/22/21	Sat 5/22/21
137			DVP #9 - Middle Weight	1 day	Sat 5/22/21	Sat 5/22/21
138			DVP #10 - Drop Test	1 day	Mon 5/24/21	Mon 5/24/21
139			DVP #13 - Bushing Data Analysis	2 days	Mon 5/24/21	Tue 5/25/21
140			DVP Signoff	0 days	Wed 5/26/21	Wed 5/26/21
141			DVP #12 - Long Term Usage	5 days	Mon 5/24/21	Fri 5/28/21
142			**Expo Website Development**	**2 days?**	**Wed 5/19/21**	**Thu 5/20/21**
143			Write Overview	2 days	Wed 5/19/21	Thu 5/20/21
144			Description of Final Design			
145			Description of Engineering Analysis, Results			
146			Key test results (shorter, probably)			
147			Conclusions + Recommendations			
148			**Technical Breakdown Video**	**1 day**	**Wed 5/19/21**	**Wed 5/19/21**
149			Draft Script for elevator pitch			
150			Storyboard the video			
151			Recording			
152			Expo Website Ready for Peer Review	0 days	Thu 5/27/21	Thu 5/27/21
153			FDR Report Develop	16 days	Tue 5/4/21	Tue 5/25/21
154			FDR Report Update	7 days	Wed 5/26/21	Thu 6/3/21
155			EXPO	5 days	Fri 5/28/21	Thu 6/3/21
156			Complete Checklist	2 days	Wed 6/2/21	Thu 6/3/21
157			FDR Report submission to Sponsor	0 days	Thu 6/3/21	Thu 6/3/21

Project: F31 Gantt Chart(new)
Date: Fri 6/4/21

Task, Split, Milestone, Summary, Project Summary, Inactive Task, Inactive Milestone, Inactive Summary, Manual Task, Duration-only, Manual Summary Rollup, Manual Summary, Start-only, Finish-only, External Tasks, External Milestone, Deadline, Progress, Manual Progress

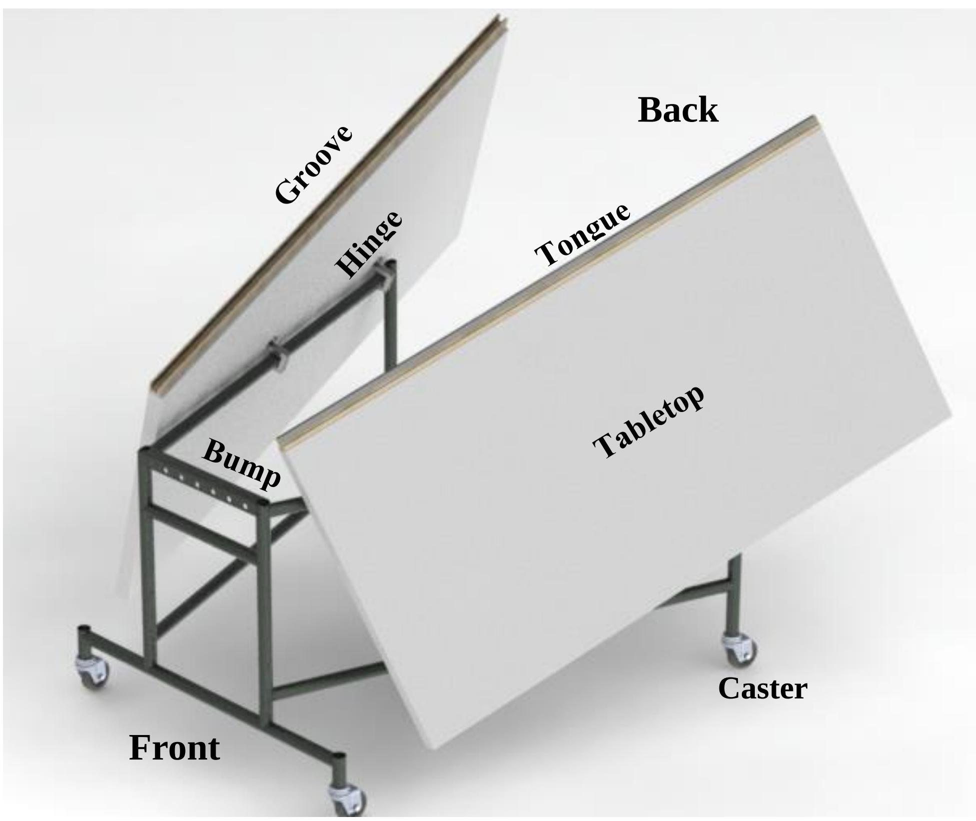
Appendix T: User Manual

TransporTable User Manual



The main actions involved with this table are deploying the tabletops and stowing the tables together. For safe operation refer to the steps given in this user manual.

Reference: Below is a labeled view of the table, refer back to this diagram to understand the terminology used in the instructions below.



Parts List

- 2 IKEA Lagkapten tabletops
- 4 Custom Steel and Ultra-High-Molecular-Weight Polyethylene (UHMWPE) Hinges

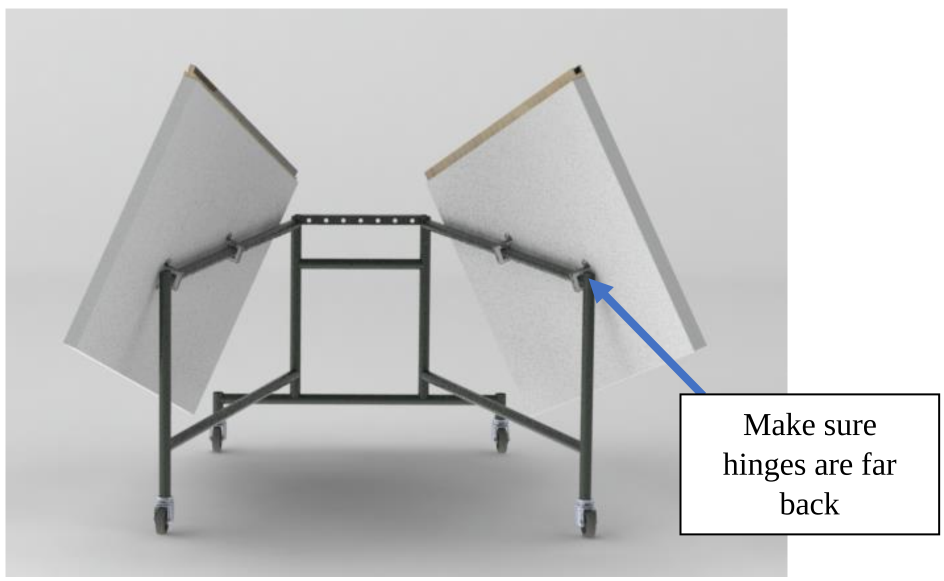
- 4 ½" Diameter screw, 3" Diameter Wheel Threaded Stem Locking Casters
- 2 Latches
- Custom Steel Frame
- Custom Wooden Tongue and Groove

Tables are preassembled, no extra assembly required. Casters may be removed if desired. No safety equipment is required to operate this table, however during some part replacement procedures, safety goggles may be required.

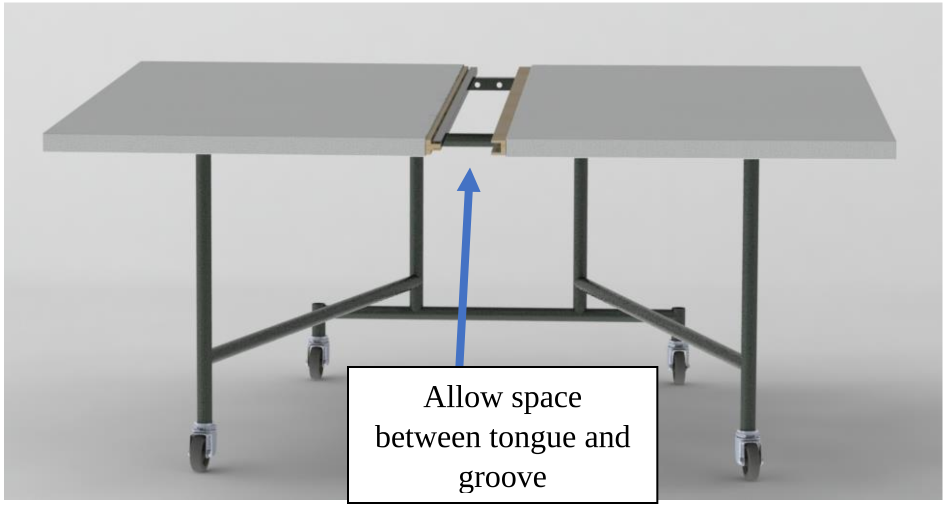
Deploying

In order to use the table, the tabletops must be deployed from their storage configuration. This is a simple process but there are a few details to note. The process is as follows:

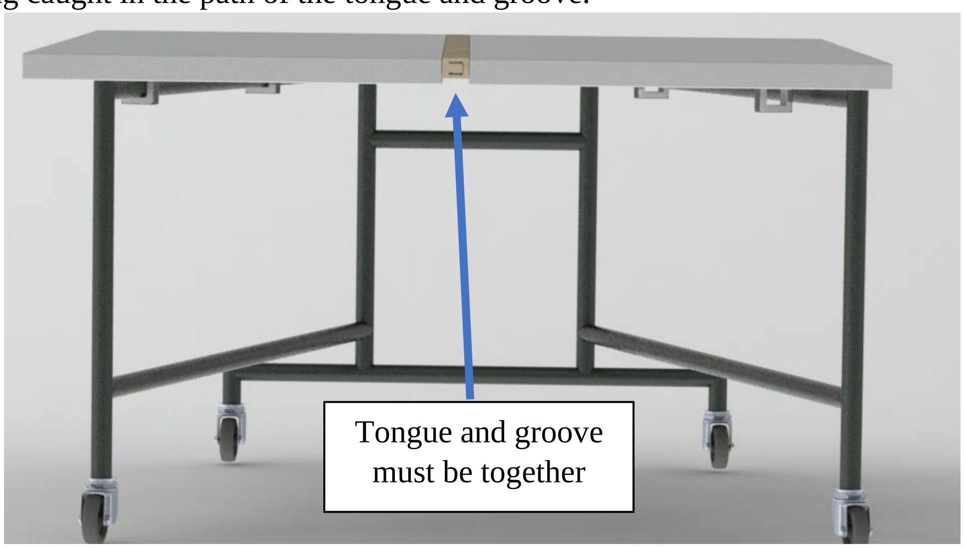
1. Place the table in the desired location. Lock down the casters to ensure the table does not move while deployed. Slide both tabletops until the back hinges are at the back of the frame.



2. Starting on one side of the table, take the tabletop and fold inwards until the tabletop is resting on the bump stop. Keep clear of the hinges to prevent any pinching. Fold the other tabletop inwards until it is resting on the bump stop. Note the positions of the tongue and groove to prevent interference when the tabletops are deployed.
   Warning: Only move one tabletop at a time to prevent overexertion. Both tabletops shown folded for demonstration purposes.



3. When both tabletops are horizontal, make sure there is nothing between the two tabletops. Slide both forward until the tongue and groove are fully interlocked. Watch for anything caught in the path of the tongue and groove.



4. Lock down the latches to prevent the tabletops from sliding. Table is now ready for normal usage.
   Warning: Do not use the table if the latches are not functioning properly.

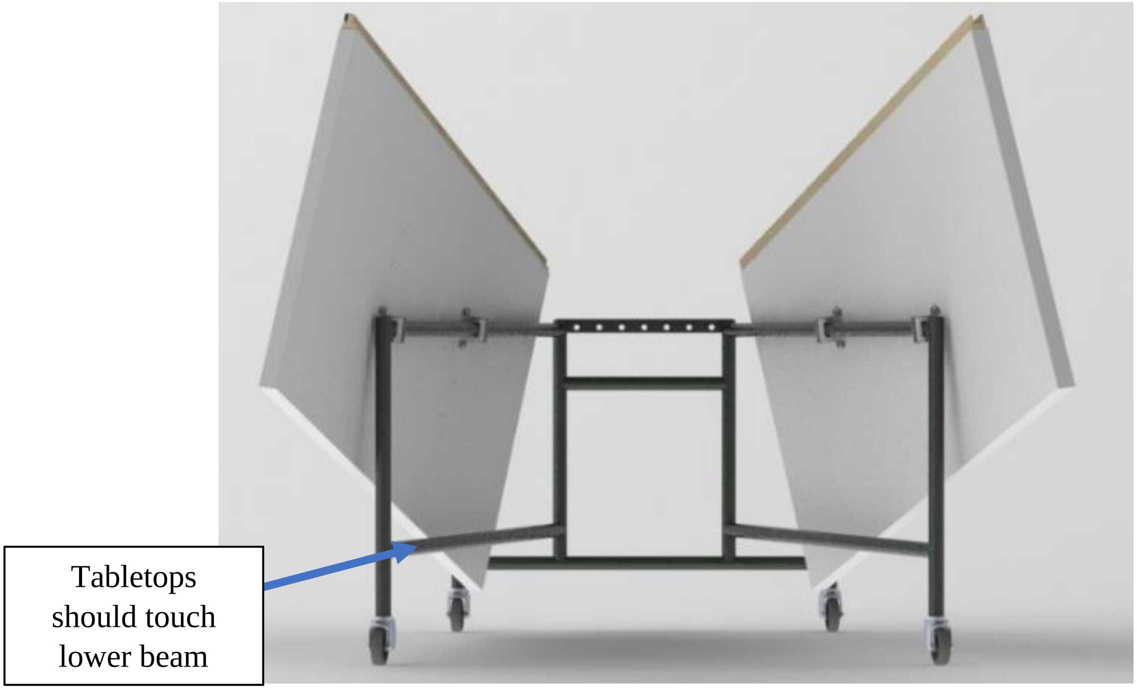
Storage

To stow the table, the tabletops must first be undeployed.

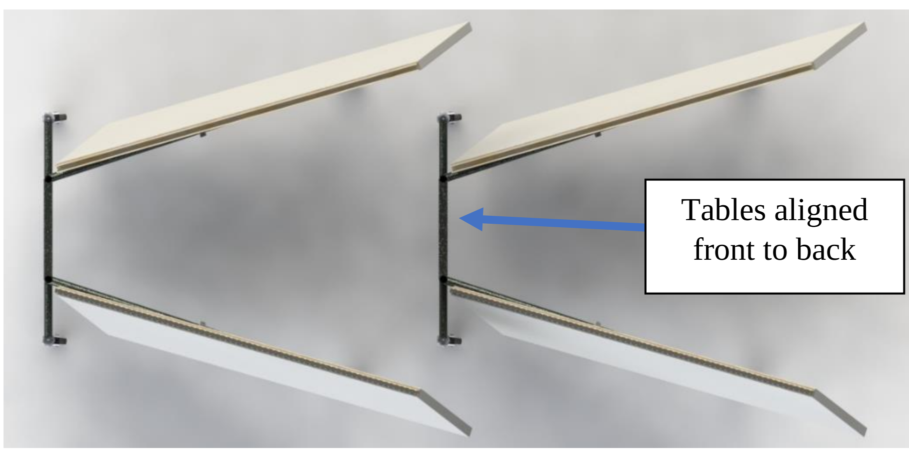
1. Unlock the latches holding the tabletops together. Slide tabletops back until the tongue and groove are free of each other. Make sure the back hinges are at the back of the frame. **Warning: Make sure there is enough space to move the tabletops back. Only move one tabletop at a time, both shown for demonstration purposes. Note the angle of the tabletops shown, tabletops will fall if unsupported.**

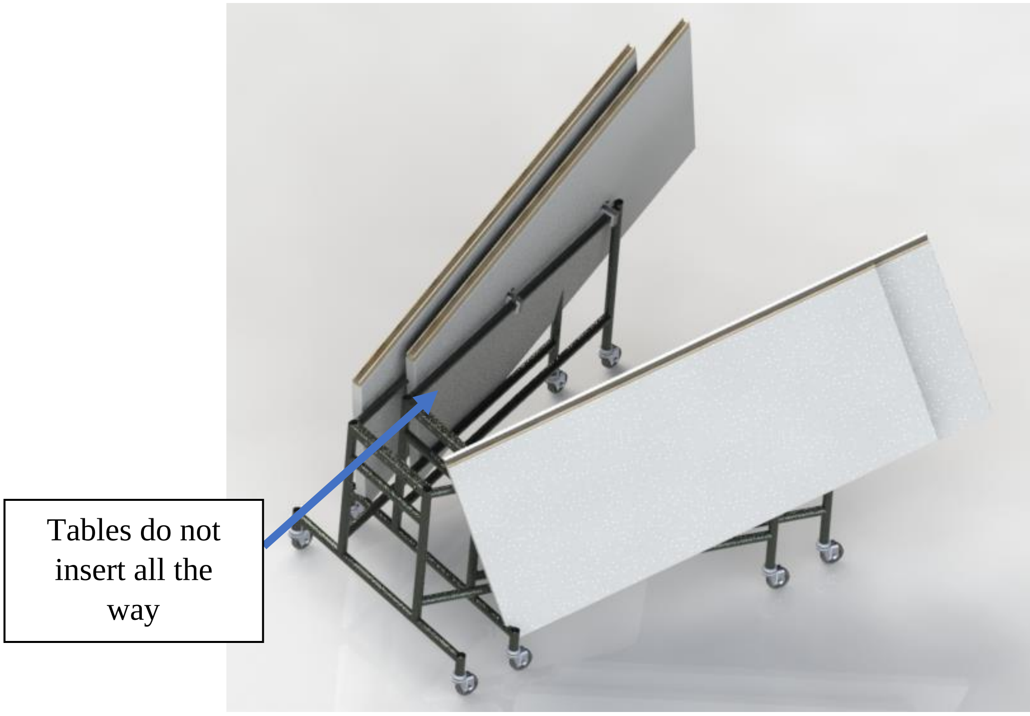
.

2. One tabletop at a time, fold tabletop over the frame until it touches the lower crossbeams of the frame. Keep clear of the hinges to prevent pinching.
   Warning: Gently guide tabletops to storage position to prevent excessive wear. Do not let go of tabletops until they are in position.



3. Unlock casters to allow the table to move. Move the table to storage location.
   To store the tables within each other, align the front of the table with the back of an undeployed table. Push table into the opening in the back until it touches the other table. Do not try to force the table to move past this point.





Maintenance

This table is designed to require very little maintenance. There are a few components which may need to be monitored. The frame paint may begin to chip after a while or if the table is used improperly. The hinges are designed to provide natural lubricity and will not need further lubrication. Other components may wear over time.

The table is meant for indoor use but can be used outdoors. Do not leave table outside if raining. Do not exceed rated weight of 200 lbs. Do not drop table from a height above 3 inches.

Common Issues

Some common issues that may be encountered while using this table are a dip developing between the tabletops, hinges becoming difficult to operate, and casters becoming difficult to operate. If a noticeable dip is seen where the two tabletops come together, it may be a sign that the latches are loose. Resecure the latches and check to see if the issue is resolved. If not, check the tongue and groove to make sure they are interlocked. If the hinges become difficult, check for any obstruction that prevents movement. Remove any object which may be stuck inside the hinges. Warning: do not attempt to access the hinges while they are in motion. If the casters malfunction, it is best to replace them with a new caster of a similar size.

Replacement Procedures

Casters
Unscrew faulty caster and replace with new caster. For best operation, use a ½” caster with a 3” diameter wheel.

Tabletops
Unscrew tabletop screws attached to the hinge mounting plate. Remove tabletop and note where the anchors are placed. Remove either the tongue or groove attached to the tabletop. Mark the anchor placement on another IKEA tabletop and install anchors in those locations. Make sure to use safety goggles when drilling the anchor holes. Attach tongue or groove to new tabletop using wood glue. Align anchors with hinge mounting plates and replace screws.

Latches
Unscrew faulty latches and replace with latches of a similar size.

The design of the table allows for easy replacement of off the shelf parts. However, the hinges, tongue and groove are parts custom made for this table. If those parts require replacement, it is recommended to return the table to the manufacturer.

Appendix U: Test Procedures and Result Reports

Test Name: Stacking Efficiency Test

Purpose: *The purpose of this test is to physically measure the assembled table dimensions to determine whether the desired stacking efficiency has been achieved or not.*

Scope: This testing includes taking measurement of 'additional length added by nesting table' shown in procedure step 5 and comparing to the Solid Works dimension which best portrays the horizontal stacking efficiency.

Equipment:

1. Two assembled table
2. Tape measure

Hazards: None

PPE Requirements: None

Facility: Leveled floor with at least 20' by 20' dimension.

Procedure:

1. Configure both table assemblies into stowed position.
2. Leave one table stationary and move the other table as far into the stationary table as possible without merging. Note that the two tables should be at equal height. An example is shown in **Figure *1*** below.

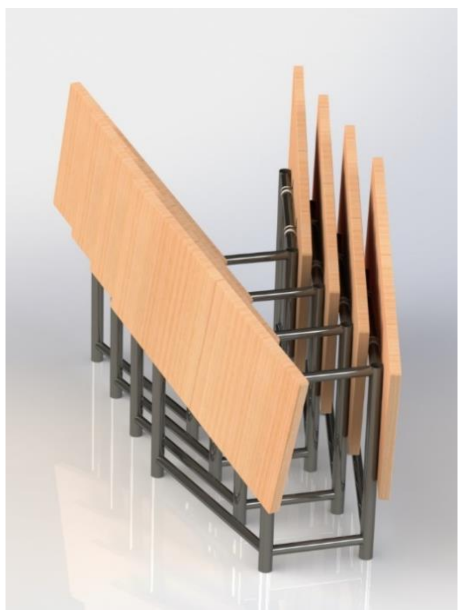
a. 

Figure 1: Tables in nested position, only two tables are necessary.

3. Use the measuring tool to measure the following lengths as marked in **Figure *2*** and **Figure *3*** below.

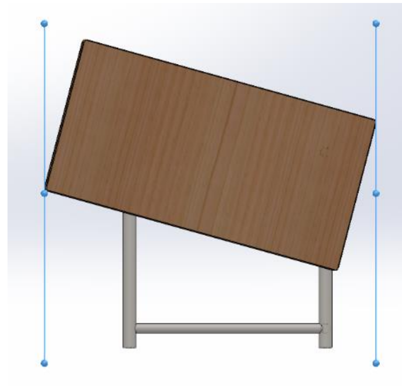
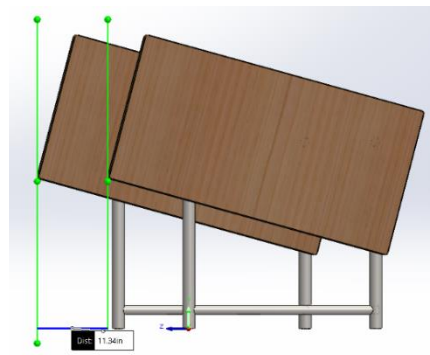

a.

Figure 2: Maximum length of one table



b.

Figure 3: Additional length added by nesting table.

4. Record the actual 'maximum length of one table', and 'additional length added by nesting table'.
5. Repeat step 3-4 on the other side of the table.
6. Record the average actual measurements of two values and calculate the % difference.

Results: Test fails if the % difference of 'maximum length of one table' and 'additional length added by nesting table' is greater than 1%.

	Maximum length of one table (in)	Additional length added by nesting table (in)
SolidWorks measurement	61.7	68.2
Actual measurement (Left)	62	69
Actual measurement (Right)	62	69
Average Actual measurement	62	69
Actual Average % difference	(1-(62/69))*100% = 10.1%	
Anticipated % difference	(1-(61.7/68.2))*100% = 9.53%	
Difference	(10.1-9.53 = 0.57%) < 1%	

Test Date(s):6/2/21

Test Results: PASS

Performed By: David Yang & Ellie Kitabjian

Test Name: Deploy/Stow Time Testing

Purpose: Verify that the table can be deployed and stowed by the majority of users within the specified time periods.

Scope: The ability of the user to adjust the table with ease between its two configurations involves the table as a whole. We anticipate that the functionality of the hinges, the stiffness and weight of both the frame and tabletop assemblies, and the intuitive design overall are important features to this test.

Equipment: Stopwatch

Hazards: Test subjects will be given minimal instructions to maintain the integrity of the test and may therefore mishandle the tabletops during the hinge motion causing them to knock the test subjects' body. They may also be pinched if their hands get in the way of the tabletops coming together.

PPE Requirements: Safety glasses

Facility: Leveled floor with at least 20' by 20' dimension

Procedure: The test should be conducted following the procedure outlined below:

1. Test subject will be given brief instructions about the function to be performed (i.e. stow, deploy) and the method in which they will be timed.
2. Once the stopwatch has been started, the test subject may begin performing the function (pictured in stages below from the stowed to deployed configurations).

3. When the motion is completed the test subject will call time at which point the stopwatch will be stopped.
4. Additional trials will be conducted with this subject, and then will be repeated with alternate subjects in the same manner.
5. The times for each trial will be recorded and organized in a spreadsheet where uncertainties will be calculated, and results will be calculated and charted.

Results: A test population of at least 7 people within our target demographic of users (Cal Poly students and professors) will be timed performing both the deploy function and the stow function a total of 5 times each. The test will produce measured results noting average times, range of times, and any outliers or notable cases. If 80% of the trials are completed in 30 seconds or less for deployment and 45 seconds or less for the Folding the results of our test will be acceptable to satisfy our deploy/stow efficiently requirement.

Subject #	Time deploying (seconds)	Time stow (seconds)
1	30	32
2	36	35
3	38	34
4	30	31
5	32	34
6	36	34
7	35	31
AVERAGE	33.9	33

Test Date(s): 5/22/2021

Performed By: Ellie Kitajibian

Test Name: BIFMA Tipping Test (DVPR #8)

Purpose: Evaluate the stability of TransporTable.

Scope: This test assesses the stability of the overall product. It primarily involves load transfer from the tabletop through the legs to the ground.

Equipment:

1. Level testing platform
2. Assembled TransporTable
3. 12" disk
4. 12 X 10 lbs. Tarp Sandbags

Hazards:

1. Falling heavy materials.
   a. Stand back from table when loading to prevent weights falling on feet.
2. Heavy loads.
   a. Use a lifting assist or other team member to avoid overexertion.

PPE Requirements:

Safety Glasses

Facility: Leveled floor, open area with at least 15' X 15' dimension

Procedure: The testing procedure has been adapted from ANSI/BIFMA X5.5-2014, which covers testing standards for desk products.

1. Place a 305 mm (12 in.) diameter disk so that its center is 178 mm (7 in.) from the edge of the top at the least stable location. If the center of the disk is greater than 305 mm (12 in.) from a corner of the top, move the disk such that its center is 305 mm (12 in.) from the corner keeping the edges of the disk equidistant from both sides of the top. Figure 1 below diagrams the test setup.

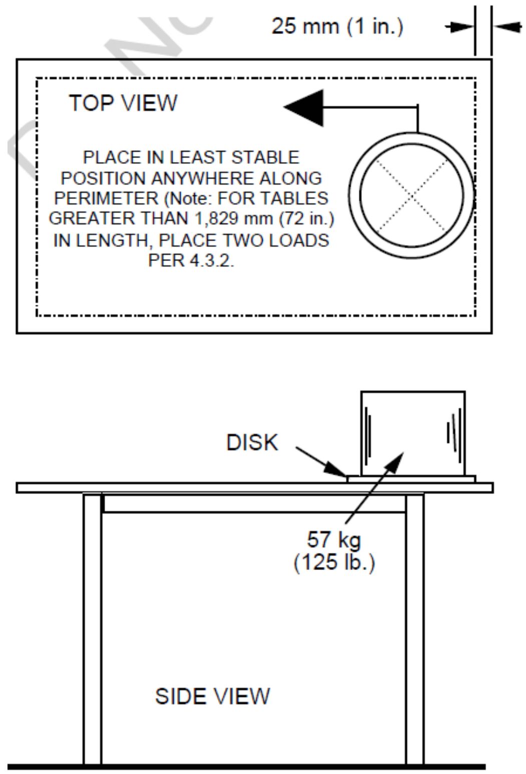


Figure 1: Diagram of load test setup. From ANSI/BIFMA X5.5-2014.

2. Place a 57 kg (125 lb.) static load on the disk(s).
3. If necessary, repeat steps (a) and (b) to verify the least stable position has been evaluated.

Passing Criteria: TransporTable will pass this test if the table remains static under load. If the table tips over during loading, the table will fail the test. Because the table is symmetrical and has an obvious corner of least stability, only one corner needs to be tested.

Test Results: 125 lb. vertical load was applied at the front edge of the table. From the load, approximately 5 degrees of deflection was witnessed majorly due to the dislocation of tongue and grove mating. No damage was witnessed, and the table was back to no-deflection state when the loads were removed. Test Passed, no further recommendation.

Test Date(s): 5/22/ 2021

Performed By: David Yang

Test Name: Concentrated Load Test

Purpose: *This tests compliance with BIFMA standard 5.2 and ensures the table will not break or deform under a large load.*

Scope: Tests load bearing capacity of the table and deflection under a concentrated load of 200 lbs.

Equipment:

1. 20 X 10 lbs. Tarp Sandbags
2. Tape measure or yardstick

Hazards:

1. Back Injury
    a. Large weight shall be lifted in a safe manner.

PPE Requirements: Gloves

Facility: Leveled floor, open area with at least 15' by 15' dimension.

Procedure:

1. Move tabletops into deployed position and engage the latch.
2. Measure distance from the center of the bottom of the rear face of the table to the ground.
3. Load weight onto center of the rear edge of table, ensure weight will not fall off edge
    a. If table starts to deform significantly before full weight is applied, stop test and remove weight.
4. Allow weight to remain for 10 minutes.
5. Remeasure distance in step 2.
6. Remove weight and observe table deflection.
7. Repeat test two more times.

The test will fail if the table deflects more than 1/2 inch, measured as the difference between the loaded and unloaded height. Test also fails if the table is permanently affected (table does not go back to original height when load is removed).

Results: Approximately up to 101.8 lb. load was applied at the middle of the table on top of the tongue/grove mating. Beyond such load, cracking noise was heard, and the test was terminated, not meeting the passing criteria of 200 lbs. See recommendation for this issue in the verification chapter of the report for further recommendation.

Test Date(s): 5/22/2021

Performed By: David and Ellie

Test Name: DVPR #10 – Drop table from 2.4 inches above the ground

Purpose: To test the table assembly's durability as required per 2014 BIFMA X5.5 Desk and Table products.

Scope:

Perform multiple drop test of the table assembly from a measured 2.4 inches height from the ground. Visually inspect any damage on the table assembly from the dropping.

Equipment:

1. Tape measure
2. Complete table assembly

Hazards:

3. Pinch point
    - When grabbing the table assembly to lift up, make sure your hands are free from possible pinches from the table components.
    - When dropping the table to the ground, make sure nothing is underneath the dropping point.
4. Eye hazard
    - Protect eyes from any flying debris from table damage.

PPE Requirements:

Gloves
Safety goggles

Facility:

Leveled floor, open area with at least 15' x 15' dimension.

Procedure:

1. Visually inspect any abnormality of the table assembly.
2. Physically inspect any abnormality of the table assembly by grabbing and wiggling multiple components with hands to check the assembly has no defect.
3. Gradually lift up the table up from the ground.
4. Second person shall measure the distance between the most bottom height of the table (contacting point) to the ground using the tape measure. Contacting point will most likely going to be one of the caster wheels, and this distance shall be 2.4 ± 0.1 inches.
5. After clearing the second person out of the dropping site, first person drops the table assembly to the ground. No slam-dropping, but with a casual let-go motion.
6. Perform steps 1 & 2.
7. Repeat steps 3 to 6 for four (4) times using different contacting point (i.e. caster wheel #2, #3, and etc.).
8. If no signs of defects are found from performing steps 1 and 2 during the tests, table passes the test. Otherwise, mark the test trial fail and document any findings / defects.

Pass Criteria:

Pass / no pass, binary result criteria, based on a visual and physical inspection of the table to inspect any damage or abnormality.

Test Date(s): 5/22/2021

Test Results: Table was dropped from approximately 3 inches in height for three (3) times and endure the impact with no visible damage. Test passed and no further recommendation.

Performed By: David and Ellie

Test Name: BIFMA Leg side load test (DVPR #11)

Purpose: Evaluate the strength of the leg portion of TransporTable against a static side load.

Scope: This test involves applying a horizontal load of 100 lbs per BIFMA X5.5 on the table legs to evaluate the moment resistance.

Equipment:

1. 6' long polypropylene rope
2. Hanging scale (digital or analog)
3. Assembled Transportable

Hazards:

1. Trip hazard
    a. Testing personnel might trip from pulling on the scale.
2. Heavy loads.
    a. Table needs to be lifted up to be flipped 180 degrees around.
3. Tensioned rope
    a. Check for rope defects / weak ties around the leg or the scale.

PPE Requirements:

Safety Glasses

Gloves

Facility: Leveled floor, open area with at least 15' x 15' dimension.

Procedure: The testing procedure has been adapted from ANSI/BIFMA X5.5-2014, which covers testing standards for desk products.

1. Two testing personnel lift the table in a deployed configuration up from the floor.
2. Gently rotate the tables 180 degrees and place the table down on the floor with the top portion of the table make contact to the floor.
3. Make sure there is no rocking of the table by pressing down multiple regions on the table top.
4. Wrap the rope around one of the table leg tube and make a firm tie at the end of the leg (very top of the leg to create maximum moment when being pulled).
5. Make another firm tie around the hanging scale using the other end of the rope.
6. Test the ties on the both ends by pulling the rope multiple times.
7. Apply an approximate 100 lbs load (reading from the scale) on the leg by holding on to the hanging scale and pull with the body weight. Try best to have the pulling arms positioned parallel as possible to the floor. If the table starts to drag from the pulling, have a second person hold on to the table assembly.
8. Check for deflection or abnormality on the table. If deflection is observed, log the situation.
9. Untie the rope from the leg.
10. Repeat steps 4-9 for three more legs.

Passing criteria: TransporTable will pass this test if the table remains static under load. If any signs of deflection is found during loading, the table will fail the test.

Result: All four legs were horizontally loaded with approximately 140 lbs. One of the legs showed a very slight plastic deformation which has a negligible effect on the table usage. Overall test resulted in a passing measure.

Test Date(s): 5/22/2021

Performed By: David Yang

Test Name: Long-term usage: study at table for a week (DVPR #12)

Purpose: Receive feedbacks from survey participants.

Scope: This test involves conducting survey for multiple groups of people who continuously utilize the table over five separate usage occasions. Categories of the feedbacks shall include (1) ergonomics, (2) durability, (3) complaints, and (4) extra comments. Results of the survey will be used to develop the next version of the product, or to fix any existing critical issues.

Equipment:

1. Assembled TransporTable
2. 4 chairs

Hazards:

1. No critical hazards associated

PPE Requirements:

1. N/A

Facility: Level testing platform (preferably in a studying environment, i.e. library)

Procedure: The testing procedure has been adapted from ANSI/BIFMA X5.5-2014, which covers testing standards for desk products.

1. Place the table on a leveled floor. Make sure there is no rocking and the table is not defected.
2. Four people will simulate the every-day-usage by studying on the table. Selection of the participants shall be arbitrary but variety as possible (participant height, weight, laptop usage, etc.) It is preferred to have a long simulation session to maximize the number of prospective comments from the participants, but make sure the session is at least 30 minutes.
3. Participants shall provide feedbacks on the usage survey form at the end of the session.
4. Repeat step 2-3 to have a total of five sessions.
5. Collect the participant-filled survey forms.

Pass criteria: TransporTable will pass, given no critically negative comment is provided at the end of the survey. Every feedback from the simulation shall be logged to be analyzed for the product refinement.

Test Date(s): 5/18/2021

Test Results: Test was modified to be an internal usage test. From the test, following modification/observation were made:

1. Tabletop's sliding feel across the frame heavily depends on the bushing carrier's fit. To enhance this deficiency, we have conducted test #13 statistical bushing carrier manufacturing test to derive an optimal dimension for the bushing carrier that houses UHWMPE block bushing to provide a desirable fit to run across the steel frame smoothly. Our initial concept for test #13 was to derive the tolerance for the UHWMPE block bushing presuming that the fit would depend on the block bushing itself but was able to modify the testing to aim for the bushing carrier dimension instead.

2. Updated the bump stop subassembly from a T-shape to a bent sheet metal part which significantly improved the table's stability when in deployed configuration.
3. Implemented to use anchor hardware found in Appendix I:Hardware Compatibility Test Report to install the compression latches on the side of the tabletops. Anchor did provide more sturdy connection for the table to take more loads.
4. Verified that the table frame layout does not interfere with the users' legs when using the table sitting down on chairs.
5. Tongue/groove feature still permits slops in the table and would recommend upgrading the design of the feature or modify the manufacturing process to eliminate the existing slops by providing a tighter mating.

Performed By: David and Ellie

Test Name: UHMWPE (Ultra high molecular weight polyethelene plastic) Bushing Carrier Manufacturing Tolerance Test

Purpose: To analyze the manufacturing tolerances in the bent sheet metal bushing carriers and develop a useful manufacturing tolerance.

Scope:

Measure key bushing carrier dimensions to develop a useful tolerance for the sheet metal part that will ensure a useful fit, eliminating slop while still allowing freedom of movement.

Equipment:
- Bushing Carriers
- Calipers

Hazards:

Sharp Edges: Be aware of any sharp edges left over from waterjet surface finish. If necessary, wire wheel the parts to remove sharp edges.

PPE Requirements:

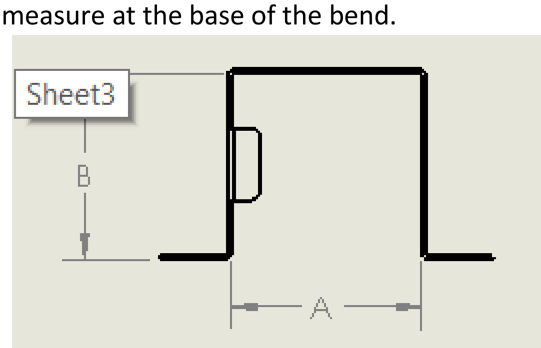
Safety glasses

Facility:

No specific facilities required.

Procedure:

1. For any bushing carriers that are assembled to tables, note the table's resistance to folding and sliding in the table below. Afterwards, disassemble the hinge from the tables.
2. Using calipers that measure to ±0.001", measure dimensions A and B as noted in the figure below. For dimension A, measure at the base of the bend.



3. After noting fits, develop both current tolerances as well as a tolerance for acceptable fitment.
4. NOTE: VP2 parts nominal dim b = 1.950"; VP1 nominal dim b = 2.00".

Results: Final tolerance dimension for the bushing carriers, and tolerance goal.

Carrier #	Dim A	Dim B	Notes
1	2.010”	1.984”	VP2 RL. Bushings are not chamfered so fit isn’t quite flush.
2	1.990”	1.960”	VP2 FL. Bushings chamfered but undersized condition means bad fit.
3	2.012”	1.940”	VP2 FR.
4	1.973”	2.019”	VP2 RR.
5	2.007”	2.030”	VP1
6	2.005”	1.981”	VP1
7	2.013”	1.972”	VP1
8	2.016”	1.952”	VP1
9	2.012”	1.966”	Unused VP2-spec

Test Date(s): 5/26/2021

Test Results: The uncertainty on dimensions A and B are ±.011 in. and ±.028 in., respectively. Dim. A should be 2.011 ± .011 in. and dim. B is 1.978 ± .028 in.

Performed By: David Yang

Appendix A: Uncertainty Calculations

DVPR # 13 ANALYSIS

USING THE SAMPLE DATA, WE WANT A POPULATION UNCERTAINTY (THE NOMINAL POPULATION MEAN HAS NO BEARING ON THE UNCERTAINTY HERE). THE POPULATION UNCERTAINTY FROM A FINITE SAMPLE IS GIVEN BY

$$U_{\bar{x}} = \pm \frac{ts}{\sqrt{n}} \quad (P\%\ \text{CONFIDENCE})$$

WHERE SAMPLE STANDARD DEVIATION "s" IS GIVEN BY

$$s = \left[\frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})^2 \right]^{1/2}.$$

THERE ARE $\nu = 8$ DEGREES OF FREEDOM (RECALL $\nu = n-1$). AT 95% CONFIDENCE, $\alpha = 0.025$ ON THE STUDENT-T DIST'N. THEREFORE,

$$t(\nu = 8, \alpha = 0.025) = 2.306.$$

AND THE UNCERTAINTY ON DIMS A/B IS:

$$U_{\bar{x},A} = \pm \frac{2.306\,(0.0146)}{\sqrt{9}} = \pm 0.011'' \qquad U_{\bar{x},B} = \frac{2.306\,(0.0366)}{\sqrt{3}} = \pm 0.028''.$$

LOOKING BACK AT THE FIT DATA, DIM. A SHOULD NEVER BE AN INTERFERENCE FIT AND DIM. B SHOULD BE A MAXIMUM OF 0.050" INTERFERENCE. ASSUMING NOMINAL DIMS OF 2", THEN

$$A = 2.011 \pm 0.011''$$

AND

$$B = 1.978 \pm 0.028''.$$

Appendix V: Final Project Budget Sheet

Appendix V: Final Project Budget Sheet

Materials Budget for Senior Project

Title of Senior Project:	F31 Transportable			
Team members:	Christopher Macias	David Yang	Ellie Kitabjian	Jung Kim
Designated Team Treasurer:	Christopher Macias			
Faculty Advisor:	Sarah Harding			
Sponsor:	Peter Schuster			
Quarter and year project began:	Fall 2020			
Materials budget given for this project:	**$1,000.00**			
CP Connect Grant	**$1,030.40**			

Date purchased	Vendor	Description of items purchased	Budget Transaction	Grant Transaction
03/01/21	McCarthy Steel	Steel Tube	$ -	$ 323.25
03/04/21	Grainger	UHMWPE Sheet	$ -	$ 42.09
04/12/21	McCarthy Steel	Steel Tube	$ -	$ 64.65
04/21/21	IKEA	Tabletops	$ -	$ 150.80
05/06/21	Home Depot	Sheet Metal	$ -	$ 24.60
05/06/21	McCarthy Steel	Base Plate	$ -	$ 19.58
05/06/21	Amazon	Casters	$ -	$ 23.97
05/17/21	Home Depot	Paint	$ -	$ 17.12
		Total expenses:	$ -	$ 666.06

Budget:	$ 1,000.00	CP Connect Grant	$1,030.40
Budget Expenses:	$ -	CP Connect Expenses	$666.06
remaining balance:	$ 1,000.00	Grant Remaining Balance	$364.34