California Polytechnic State University,
San Luis Obispo

Department of Mechanical Engineering

Senior Project

Final Design Report

Cal Poly Table Top

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Statement of Disclaimer

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Executive Summary

Since many tables currently used at Cal Poly are not ideal for active design situations, we have designed, built and tested to be used in design classrooms with an emphasis on using the tables to quickly prototype ideas. This table is a standing height table in a trapezoidal shape which can comfortably seat four people. The modular design of the table allows multiple tables to be use to create different shapes so that the tables can be used in multiple ways.

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1 Introduction

California Polytechnic State University San Luis Obispo (Cal Poly) provides an excellent engineering education, where student teams working through design processes together is a core aspect of its curriculum. To facilitate this learning experience, the university has a variety of tables to satisfy the needs of the students and faculty. After visiting a multipurpose space used at Hasso Plattner Institute of Design at Stanford (d.school), it became apparent to Peter Schuster, a mechanical engineering professor at Cal Poly and sponsor of this project, that the tables available for use in a future multipurpose room on campus either occupied too much space, were not sufficiently stable, or didn't accommodate users in a standing/high-stooled position. Dr. Schuster introduced this problem to the Mechanical Engineering Department of Cal Poly in the form of a senior project. A team of three students was formed and given the task of designing and fabricating a stable collaborative design work table to be used by future engineering students and faculty that can be manufactured with campus resources, last 10 years, and most importantly minimize space required for storage. Through re-scoping of the project, the team now consists of two members.

1.1 Project Overview

The goal of this project was to design, fabricate, and test a table that suits the needs of future Cal Poly students and staff. Though the market is flooded with thousands of table designs and patents, our project sets out to find a way to take the best aspects from a variety of designs and incorporate them into a single product to meet the needs of our customers. This project did not seek to reinvent the table or its storage mechanisms, but to draw from design features that currently exist and incorporate them into a platform on which future design work can be performed within an easily adaptable space. We achieved this goal and presented our final table to the Mechanical Engineering department on June 2, 2017.

1.2 Stakeholders

The worktable that we intend to design will be a valuable tool for future students working in a collaborative workspace located in the Bonderson Project Center (Building 197-104). The end users of this product will largely be California Polytechnic State University faculty and future design students; however, the school's technicians that will manufacture the tables were also taken into consideration. Faculty will likely be involved in much of the classroom setup and teardown. If the tables required too much effort to reconfigure and move into position, then the instructors will not be as inclined to make full use of the collaborative environment. In addition to faculty, the primary users of the tables will be student design teams. If the table is not sturdy enough or ergonomically

oriented, then it will not foster a productive collaboration environment and will likely frustrate the students using it. These students want a table that fosters a creative environment, and allows the unfettered discussion of ideas. Finally, the technicians that will be building the tables must also be considered throughout the design process. If the table requires an excessive number of custom built parts, or is difficult to repair, then the act of building and maintaining the tables might not be deemed worthwhile by both the student technicians and those funding them. If the table is too difficult to build, then the labor cost will increase, possibly resulting in making the tables too costly to continue to manufacture. Furthermore, if the table is difficult to maintain, then it might not last much longer than one duty cycle. Parts should be easily acquired and replaced, as necessary.

1.3 Special Thanks

We would like to pay a special thanks to all who have worked on this project. Throughout this year, many people have worked on this project in many different aspects. We would like to take the time to give thanks to them for all that they have contributed to this project and shaping the design process.

First, thanks goes out to Alejandro Gonzalez-Smith and Brian Paris for the work that they did early on in the project to help with the initial designing of the table. Their help as project members during the first two quarters of this project was necessary to develop the initial design of this table and help to realize that design. Without them, the table would not resemble its current form.

Second, we thank Dr. Peter Schuster and Sarah Harding for their guidance that they have provided throughout this year on this project as they acted in both advisors and sponsors throughout the year. We hope that our final table satisfies your expectations for this project.

Next, we would like to pay thanks to everyone who helped out during the manufacturing process. We thank all of the shop techs in the Hangar and in Mustang 60 for providing us with their expertise and helping us to build the table in a more efficient manner. We also thank Amy Wilson and Amanda Meares for helping to shape and finish the final surfaces.

Lastly, we give special thanks Kyra Schmidt for her hard work on welding the final frame together. Your willingness to share your abilities in the shop with us to weld our table is so greatly appreciated and we would not have been able to complete this project as well without you. Your dedication to welding the frame and doing such a brilliant job allowed us to have a polished final product which we would not have had otherwise.

2 Background

This section details the background research conducted to gain inspiration for our ideation sessions. We collected data on tables available on the market and already in use on campus. We studied other related devices whose designs could be incorporated into our own. While looking at table designs and their performance, we will be considering the following features listed in Table 2.1.

Table 2.1: Exemplary features of tables.

Feature	**Rationale**
Stability	A table must be very stable so that groups can work collaboratively on the same surface without disturbing other members of the group by shaking the table.
Strength	A table should be strong enough to support the weight of people leaning on the table as well as the items, which the people working at that table require to work effectively.
Aesthetics	A table should be aesthetically pleasing so as to not detract from the design process.
Storability	A table should be easy to store and should have a small storage footprint.

Additionally, we surveyed ME students and staff around campus about desired table features, the results of which are summarized in the Customer Requirement portion of Section 3. Lastly, we investigated ergonomic considerations to ensure our designs have a comfortable human interface. Along with the examples presented in this section, many more were evaluated for their positive and negative attributes.

2.1 Table Types Overview

The table industry is vast. With different applications for every nearly table, we will attempt to narrow our focus to tables which are currently used for design projects, such as work tables, workbenches and the existing tables on campus. Within the worktable industry, most tables are able to support anywhere from 500 to 2,000 pounds [13]. Throughout the course of our research, we have reduced the design of tables into 8 main categories evaluated in Table 2.1.

Table 2.2: Pros and cons of consumer tables.

Type of Table	Example	Pros	Cons
Static - Legs on Outside [16]		Rigid.	Difficult to store.
Static - Center Support [1]		Social settings. Can have seats surrounding it	Unstable. Easily wobbled. Difficult to Store.
Folding Legs - Connected Legs [13]		Very strong. Quick setup.	Cannot be seated at the end of the table. Generally not aesthetically pleasing.
Folding Top - Tennis Table [7]		Easy storage. Interesting design.	The attachment point between surface and legs may be unstable.
Scissor Mechanism [14]		Easily folded.Easily stored.	Cannot be seated at the end of the table. Tends to wobble.

Table 2.2: Pros and cons of consumer tables.

Type of Table	Example	Pros	Cons
Table with Leaves [22]		Expands surface area.	Leaf or leaves must be stored.
Folding – Card Table [20]		Stores small.	Not necessarily sturdy.
Static With Wheels [21]		Sturdy/internal storage	Not compact

2.2 Cal Poly Tables

We studied the tables currently in use at Cal Poly to assess their functionality. We found that most measured at a height of 29.5 inches, which is designed to be used by a person who is seated in a standard chair. Those that are optimized for use with a stool are either too bulky or too unstable to be used in a reconfigurable design room. We made note of the stability, potential storage mechanisms, mobility and configurability of the different tables we surveyed. Below are some examples of tables, which exhibit some, but not all, of the desired features listed in Table 2.1.

While most of the tables used around Cal Poly are at a height more suited for working in a seated position, there are two tables found on campus that are more stable than the many standing height tables studied. These tables are the first highlighted in this section.

The tables in the Bonderson High Bay are at an ideal height for a standing/stooled workspace as seen in Figure 2.1. These tables are also very stable and easy to maneuver around the room. Conversely, they are not designed in a way which would allow students to comfortably sit on stools while working due to the limited leg space. The worktables are also not large enough, at 2'x5', to be a comfortable workspace for four people. Discussion would be possible, but each student would

lack the space to effectively do any sort of individual work without encroaching on the workspace of others. This is an example of the "Static With Wheels" type of table from Table 2.2.

Figure 2.1: Worktable located in the Bonderson Project Center High Bay.

In the Robert E. Kennedy Library, there are a variety of Lifetime tables used for various displays on the second floor of the library. One style of table has features such as: adjustable height, plastic surface and a folding mechanism for storage as shown in Figure 2.2. This table was not as stable, nor as aesthetically pleasing as others located around campus. This table does have a short set up/take down time of less than 30 seconds. This table also has a very high weight capacity at 1200 pounds [13]. This is an example of the "Folding Legs" type of table from Table 2.2.

Figure 2.2: Adjustable height plastic table at its tallest height.

In the Bonderson Project Center, room 104, there are collapsible, folding tables made out of particle board, which are easy to reconfigure. A problem with the deployment mechanism occurs when it often fails to trigger properly, making a quick folding of the table surface difficult. The deployment mechanism seen in Figure 2.3 is one that uses a cable to engage or disengage locking pins. These tables are also reasonably unstable because they are supported at just two locations and can collapse if they are not properly locked into place. This becomes dangerous for users who may choose to sit on the tables instead of sitting in chairs at the table. This is an example of the "Folding top" type of table from Table 2.2.

Figure 2.3: Table located in the Bonderson Project Center room 104, a collaborative space often used for group work and club meetings.

In Kennedy Library, there are tables located in the collaborative work environments called fishbowls. These tables are large, curved and heavy, which makes it difficult to reconfigure the space quickly if there is only one person available to complete the task. The fishbowl tables have fixed supports, making the tables very inconvenient to store, as seen in Figure 2.4. These tables are extremely strong and stable, with the ability to support three people's entire weight (roughly 500 lbs.) without wobbling. This is an example of the "Static-Lets on Outside" type of table from Table 2.2.

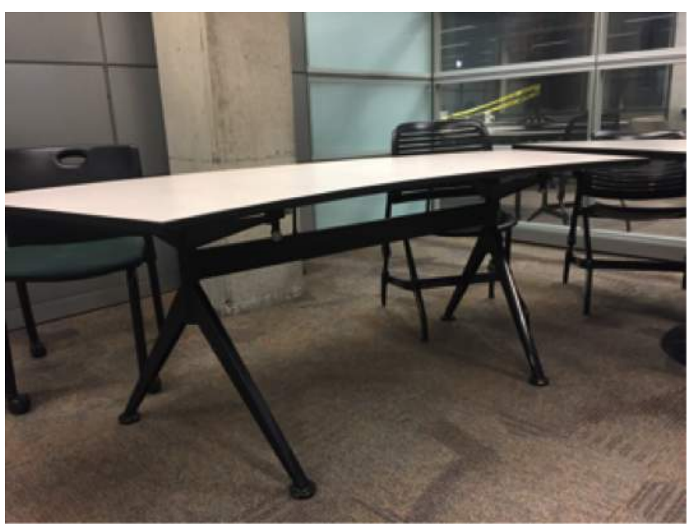


Figure 2.4: A table used for collaborative work in the library fishbowls in the library at Cal Poly.

The Advanced Technology Labs at Cal Poly have tables which can store compactly. As seen in Figure 5, eight tables may be stacked on top of each other while only taking up the footprint of one table. The tables used in this building are sturdy and stable. The major downside is that these tables are heavy. Often it is difficult for a single person to move the tables around the room, which makes reconfiguring a workspace difficult. This is an example of the "Folding Legs" type of table from Table 2.2.

Figure 2.5: A table used in the advanced technology labs, which stores easily [18].

The tables around Cal Poly are not the only tables with notable design flaws that make them less than ideal for a collaborative work environment. Since most of the tables around campus are at a height optimized for seated work, further sources must be consulted to get a better idea of the tables that exist at a raised height.

2.3 Tables on the Market

Tables outside of those found on campus were discovered through surveying videos of collapsing mechanisms of tables online, as well performing further research on table brands which are found on campus. These tables were selected for their interesting design and their functionality.

For example, Lifetime is known for producing sturdy, folding plastic tables like the one seen in Figure 2.6. With weight capacities of up to 2000 pounds, Lifetime's range of tables is notably easy to store [13]. The only downside to the lifetime tables is the plastic surface, which can be easily scratched and stained, leading to the table being not aesthetically pleasing. This is an example of the "Folding Legs" type of table from Table 2.2.

Figure 2.6: A Lifetime collapsible round table. 2.6

The Keter worktable is notable for its quick deploy mechanism. With a 30 second setup time and an ability to support up to 1000 lbs., the Keter folding worktable has a strong design [12]. Other than this, the Keter table is not the most aesthetically pleasing table on the market, as seen in Figure 2.7. It also does not accomplish the task of being able to comfortably seat/stand four people working in a common area. This is an example of the "Folding Legs" type of table from Table 2.2, with a modification on the deployment and locking mechanism.

Figure 2.7: The Keter worktable, which sets up in 30 seconds.

The Black and Decker Workmate is a collapsing workbench, which can support at least 450 pounds [5]. It folds down to an 8 inch height and can expand to a height of 29.5 inches [6]. This worktable provides a good example of a compact folding mechanism, seen in Figure 2.8, which could be a basis for a table design. This is an example of the "Scissor Mechanism" type of table from Table 2.2, with the addition of a folding and locking mechanism at the base. To lock its legs in place, this portable workbench used a semi-circular hard plastic component with flat regions on its ends allowing the bottom legs to friction-lock into the two possible positions. Notably, this mechanism requires no moving parts to lock or disengage other than the leg itself.

Figure 2.8: Black and Decker folding worktable.

A creative folding mechanism is displayed in Figure 2.9. Without knowledge of the weight capacity and overall stability of this easel-style table, we cannot make any definitive remarks about the functionality of the table. However, its interesting folding mechanism is something to consider when designing a new surface. This is an example of the "Folding Top" type of table from Table 2.2.

Figure 2.9: A creative folding mechanism.

2.4 Relevant Designs

Tables were not the only sources of inspiration we gathered before moving forward. We looked for many possible objects and devices with storage mechanisms that could potentially be utilized

in our solution. Our research consisted of investigating folding mechanisms, portable items, and other types of furniture. Table 2.3 below highlights and describes some of our findings for design considerations.

Table 2.3: Examples of possible relevant designs.

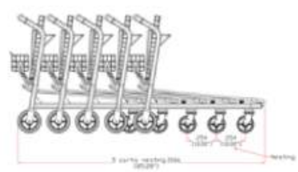
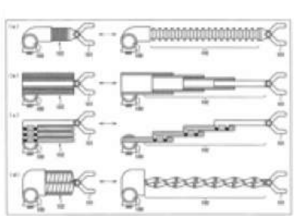
Feature	**Rationale**
 Nesting shopping carts [19]	Shopping carts designed in such a way that they nest together for compact storage when not in use. This method seems to be quite good at minimizing footprint since so much interior space is occupied by other carts.
 Umbrella folding mechanism [17]	The structural and mechanical components that comprise an umbrella is a rather simple bar linkage allows for a drastic change in size from its stored to open states.
 REI trail stool [3]	This compact camping chair uses a single component to rotate all of the legs simultaneously into similar planes.

Table 2.3: Examples of possible relevant designs.

Feature	**Rationale**
 Hinge pivot and slider mechanism on portable table	The black component shown acts as both a pivot junction for the two supporting members as well as a slider along the leg. This dual-action folds the table in a short self-contained stack.
 Metal bar stool [4]	This stool is a good example of the type of stools we may expect to see being used in the future design space. They can also stack vertically to reduce storage footprint.
 Hinges/pins of various types [8]	Hinges and pins of different styles were investigated for their unique characteristics. For example, we looked at spring-loaded pins used in telescoping rods, such as in a crutch. We also looked at hinges that had lockable positions or had torsion springs to possible ease configuration.
 Telescoping mechanisms [9]	We investigated possible mechanisms for expanding/contracting linkages. The most common and useful designs are telescoping rods, sliders, 4-bar and scissor linkages.

With the background research and findings in mind, we have a created a solid foundation from which to proceed.

3 Objectives

Currently, tables used in collaborative workspaces on the Cal Poly campus are either not stable or not portable enough to foster a productive environment. Design students need a way to collaborate on projects while still being able to reconfigure a room to allow it to be multipurpose. We intend to design and fabricate a worktable to be used in Cal Poly design spaces that is cost-effective, stable and robust, while being portable and stores compactly.

The ultimate goal of this project was to produce a functional prototype to be demonstrated and initially evaluated at the Senior Project Exposition hosted by Cal Poly on June 2, 2017. This prototype was to satisfy the customer requirements to the best of our design ability in compliance with the engineering specifications. The success of the project will be determined by testing the compliance of the final prototype to the engineering specifications.

3.1 Customer Requirements

Below is a brief list of important customer requirements to be met as defined by the sponsor.

The table must:

- accommodate four users in a high-stooled or standing position
- reduce in footprint for storage
- be reconfigurable by a single user
- be built to last for 10 years
- support 500 pounds of vertical or 200 pounds of horizontal load
- have an aesthetic appeal
- be manufacturable with available Cal Poly resources for less than $250 per table including labor
- have a surface that does not degrade with expected use or is cost-effectively replaceable

Additionally, there are many customer desires that are less critical to incorporate into the design but should still be considered because they may improve the final product and increase user satisfaction. Below is a list of customer wants gathered from surveying students and staff.

The table could:

- be reconfigurable by a single user in less than 30 seconds
- adjust in height and/or angle for drafting
- accommodate users in chairs
- contain interchangeable surfaces with various functions
- have integrated power outlets
- withstand four users sitting on it
- follow ADA guidelines for furniture
- be usable outdoors
- have an area to attach workpieces with clamps

These customer needs and wants are used to develop quantifiable engineering specifications. As part of the design process, utilizing a development tool called Quality Function Deployment (QFD) helped us determine the most important customer requirements and engineering specifications to meet. This will drive our design efforts to best meet the needs of the consumer as well as serve as a framework for judging the success of the table produced.

3.2 Quality Function Deployment

Quality Function Deployment (QFD) is a tool our team used to translate customer requirements, defined by Peter Schuster (as a representative for ME staff) and by students, into engineering specifications, which can then be used to tailor the product design. The product of QFD is known as the House of Quality, which can be found in Appendix A. Inside the house are various weighting systems that evaluate the customer's requirements relative to how they can be designed and quantified, current similar products, and who the requirement affects. The results contained in the house indicate the relative importance of customer requirements and of meeting certain engineering specifications. For example, we can see from the customer requirement section that the stability of the table is highly correlated to many of the possible engineering specifications. Additionally, we note that safety is critical, as having no pinch points had a very high weighted importance and that minimum load requirements must be fully met. Lastly, we can also see that the way customers interact with the table when configuring or transporting it is very closely tied to many of the customer requirements. From the QFD results, we were able to put clear bounds on our engineering specifications and assess which customer requirements are most important to be incorporated into the final design.

3.3 Engineering Specification List

Table 3.1 is a list of engineering specifications derived from the QFD that includes numerical design requirements, tolerance, risk, and compliance testing for our final product. The requirement and tolerance columns apply numerical bounds for each parameter to lie within. The risk column assesses the anticipated risk of not achieving the specification. Low (L) risk corresponds to an easy to meet requirement, while Medium (M) and High (H) risk specifications might be harder to meet. On the far right is the compliance column, which describes how product will be tested to ensure it meets the specification. (I) indicates visually Inspecting the product to ensure it meets the criteria, (A) is Analyzing with numerical calculations that the specification will be met, (S) denotes a specification whose requirement is justified from a Similarity to existing designs, and (T) requires experimentally Testing the specification for compliance.

Table 3.1: List of engineering specifications.

Spec #	Parameter Description	Requirement or Target	Tolerance	Risk	Compliance
1	Table Height Range [in]	36-39	WITHIN	L	I
2	Table Width Range [in]	48-54	WITHIN	L	I
3	Table Depth Range [in]	24-34	WITHIN	L	I
4	Occupancy [#]	4	MIN	L	I, T
5	Storage Area [# tables per area]	10 tables in 10'x5'	Min	M	A, T, I
6	Persons to Configure [#]	1	MAX	M	T, I
7	Steps to Store [#]	4	+1	M	T, S
8	Set-up time [seconds]	60	MAX	M	T, S
9	Pinch Points Accessible to Fingers [#]	0	MAX	M	I, T
10	Vertical Load [lbs.]	500	MIN	M	A, T, S
11	Lateral Load [lbs.]	200	MIN	M	A, T
12	Vertical Tipping Corner Force [lbs.]	200	MIN	M	A, T
13	Deflection from static loads [in]	1/4	MAX	M	A, T, I
14	Deflection from dynamic loads [in]]	1/8	MAX	M	T, I
15	Life [years]	10	MIN	M	A, S
16	Price [$]	250	MAX	M	A, S

The first five specifications address the size requirements of the table that must be met. Specs 1-4 are easy to achieve and reflect how four users must be able to work comfortably and have enough personal space for themselves and personal items. After some physical modeling the table with was increased from a range of 36-42 inches to 48-54 inches to allow for a less cramped work environment. Number 5 establishes a minimum storage requirement for a set of tables. We aim to design our table in such a way that you can store significantly more than 10 in the storage footprint, but feel that 10 is a reasonable minimum that must be achieved.

Specifications 6-9 reflect the parameters that require the user's input to manipulate the device. The device must be adjustable from its usable to storable configuration by one user in 60 seconds.

Ideally, it would require less than four steps to adjust the table from one form to another, but we believe five steps is an adequate maximum. Since our QFD showed a high importance for safety and minimizing pinch points, we will attempt to eliminate pinch points by design in all possible instances.

The next five specifications, 10 through 14, put bounds on the applied loads and deflections that the table should allow. After our background research phase, we believe that the listed loads are what we would expect the table to encounter with a factor of safety included. The applied loads are assumed static in most instances, wherein users sit on the table or are leaning into it. We defined the deflection under dynamic load by the horizontal distance the table moves during an 'eraser test'. This test will be conducted by placing the table against a wall with a mounted measuring device and observing the displacement while a user erases paper on the surface. The table should not deflect more than a 1/4 inch under static load and not more than 1/8 inch during the eraser test. These will be important metrics for safety and rigidity.

Lastly, specifications 15 and 16 limit the cost per unit and require that the table last sufficiently long to be cost effective for Cal Poly. We would like the final prototype product to cost less than $250 for parts and labor and have a life of 10 years. The price specification is labeled as medium risk because in our judgment, this may prove difficult to meet because labor is expensive. All of the parameter requirements and tolerances were derived from the QFD and background research, but may be subject to change as the design process continues. We will consult the sponsor if we desire to adjust any of these values.

3.4 Specification Rationale

Any specification for an engineering design must be justified and related to customer requirements. Anything else is superfluous and adds unnecessary cost and constraints to a design project. Below we will discuss the rationale behind each of our requirements, and why they need to be considered in our design process.

3.4.1 Footprint

While a new engineering building is being proposed, our completed product will likely be used primarily in room 104 of the Bonderson Project Center (building 197). Based on enrollment in our current design class, we anticipate that 10 tables will be needed for day-to-day use, while more may be necessary for special events. The default of ten tables will allow at least eight teams of four students each (32 students expected per lab) to work, while still allowing the instructor to have his/her own desk, and allowing for an extra table for various uses such as a craft supply station. We intend to store 10 tables in an area of roughly 50 square feet. This number was decided upon by comparing current storage footprints as shown in Table 3.2 to the currently available storage space in the wing of Bonderson 104. Our storage footprint only includes the expected space to store the tables, and we decided on a smaller number to allow extra room for stools and other furniture, along with potentially more tables, to be stored in the same area. Storage footprint refers only to the

floor space required to store the tables. The storage height may vary depending on the mechanism by which the table reconfigure which will be determined as our team continues through ideation and detailed design.

Table 3.2: Storage footprint of existing tables.

Table	Storage Area of 10 Tables	Storage Height	Free/Lean
Bonderson 104	9'x9'	50"	Free
High Bay	5'x15'	39"	Free
Lifetime (Rectangular)	2'x5'	30"	Lean

3.4.2 Height

We ultimately decided a height of 36 inches would be an ideal height for the worktable, as that is the elbow height of the average female [15]. This height is also the standard counter height [2], which means that it is a height, which is known to be conducive to working. By selecting this height, the table should be accessible to most customers and comfortable for at least half of the population. Erring on the shorter side allows shorter customers to feel more comfortable while using the table, as it is not above their natural reach, while taller customers are still able to make use of the surface. Although this could potentially cause discomfort for taller users standing at this table for an extended period of time, the use of stools could prevent too much discomfort. Shorter users can also use stools to reach the surface more comfortably.

3.4.3 Table Stability

The portable worktable should have two main stability considerations. First of all, our table will be evaluated using the following static stability criteria; the table should deflect no more than 1/8 of an inch under a 500 lb. load located at the middle of the table. This was decided to ensure the table would not become warped or unusable when students inevitably decide to sit on the table surface during design sessions. Although this is not the table's intended purpose, we must consider that the end user might not use the table as we expect. In addition to the static stability criteria, we also have a dynamic stability criteria: the table should move no more than 1/4 inch in any direction when the average user attempts to erase something on the table's surface. In group environments, the work of others should not be impeded or delayed by the actions of one member. The table should be stable enough to limit, or dampen the motions of one user. Numbers regarding the specific force and frequency will be determined as we move into the testing phase. If the table does not meet these requirements it will be frustrating to use, and other, more stable, options might be chosen over it.

3.4.4 Weight Capacity

The portable worktable should be able to support a minimum of 500 lbs. without permanent deflection or collapsing (if the table uses that mechanism), as students may sit on the table surface. As a stretch goal, we would ideally be able to support upwards of 1000 lbs, as multiple team members might sit on the table surface at the same time. We measured the force exerted by leaning on surfaces at different heights in Table 3.3 to estimate the potential forces that the table may be exposed to with standard use. By leaning on the table, there is the opportunity for more than 440 pounds to be exerted on the table. This, along with the fact that tools and projects of varying weights will be placed on the table surface, plus a factor of safety led us to the initial estimate of 500 lbs. at any location.

Table 3.3: Vertical Force Exerted [lbs.] When Leaning on a Surface

Surface Height	**Alejandro (72")**	**Brian (69")**	**Kelsey (63")**	**Alana (60")**
37.5" - Light Lean	60	35	50	35
37.5" - Full Lean	80	40	70	45
39" - Light Lean	70	35	60	32.5
39" - Full Lean	110	40	90	40

3.4.5 Durability

Although the table's lifespan depends on how it is used, we expect our table's frame to last 10 years minimum, barring extreme usage. This includes proper use of whatever compacting mechanism we employ and no loading above the specified weight capacity. Our rationale behind these long lifespans are that our customers will not want to pay to replace or maintain the worktable more often, and our end users will not feel comfortable working on a table falling into a state of disrepair.

3.4.6 Ease of Repair

The portable worktable should be easily repaired as defined by simple replacement of broken parts with off the shelf items. A modular nature should make it so that parts should not require major disassembly of the entire table to replace. Being easy to fix/maintain ties into the durability and longevity of the table, as being easy to repair removes the need to replace the entire table if one subsystem starts to malfunction. Standard, or one part repairs should be able to be performed by a semi-knowledgeable worker within an hour, as we do not wish for our tables to be out of commission for extended periods of time, nor do we want the labor cost for repairs to be excessive.

3.4.7 Configurability

The mechanism by which the table can be reconfigured between its extended and storage states should be intuitive, usable by one person, and take less than a minute to perform. The average user will not be trained on table disassembly procedure, nor will they likely have access to the user manual, so the transforming mechanism should not be some sort of puzzle. In addition, a simple design will likely be easier to maintain. Furthermore, by not requiring multiple people to reconfigure, a lone instructor, or small group of students could configure an entire room without the need for additional assistance. Finally, being quickly reconfigurable reduces the amount of time wasted setting up the workspace, and maximizes the time spent actually making use of the design environment.

3.4.8 Capacity

The portable worktable should be able to seat 4 design students comfortably. This is because many typical design teams formed on the Cal Poly campus consist of 3 or 4 members. Larger teams might be able to combine tables (depending on the final design) but the table will primarily be designed for smaller teams. Although research has been performed regarding the ideal size of a table, it has been discovered that according to one study, "the size of the interactive tabletop does not affect the speed of task completion while the group size does" [11]. Due to this finding, as long as the table can comfortably fit all group members, productivity should not greatly increase with a larger surface. Another study concluded that "larger tabletops do not necessarily improve collaboration" [10], as having a larger surface might distract from one's collaborators. Although these tests were performed with an interactive digital work surface, the same basic principles should apply to a less advanced work surface.

3.4.9 Safety

The portable worktable should minimize pinch points and sharp edges. Ideally, no pinch points would be exposed; however, the feasibility of this depends heavily on the method by which the table compacts. For example, if the surface is foldable, then, any seam would potentially become a pinch point during reconfiguration.

3.4.10 Cost

The portable worktable should cost less than $250/table to manufacture. This cost includes both materials and labor by shop technicians. This price point was requested by our sponsor, and further justified by the fact that we wish to be able to produce multiple tables in an affordable manner. Our overall budget is around $1000, so we have roughly $750 for research, prototyping, and testing to leave us with enough for our final product

3.4.11 Portability

The portable worktable should be movable by one person, and easily movable by two people. The rationale for this is that if the table requires too much effort to move, it will likely be left in one location, negating the entire purpose of the collapsible and portable mechanism. Portability is key in allowing the room to be multipurpose, instead of simply being a design only workspace. This customer need can be further quantified with a force required to slide or fold the table (as determined by testing) or an overall weight (if the table is to be lifted or carried).

4 Method of Approach

Our team intends to approach this design challenge using a slightly modified version of the classic design process as detailed below. We determined that although the classic method had many good points, but it was not specifically tailored to our project's needs.

4.1 Idea Generation

Hundreds of sketches were generated before being narrowed down first through feasibility studies and Pugh matrices and then through calculations and solid computer modeling to give a better idea of the viability of each top design.

Ideas were generated through seven ideation methods, each of which occurred at its own session. With dozens of drawings of tables created, ideas were combined based on their feasibility and their desirable features in order to generate designs of tables which were more optimized for the project. The ideas explored throughout this process can be seen in Appendix B.

The very first ideation session was a brain writing session where each team member came up with a preliminary idea for the table and sketched it in their logbooks as seen Figure 4.1. For the most part, the ideas drawn in this session were the brainchild ideas of each team member based on time spent researching. The sketches were then passed around to each team member who would add their own input on the design, either to clarify how the design functions or to provide another similar solution which may not have been considered. This session generated 3 main designs with some small deviations on these designs also presented. All three of these ideas can be found in Appendix B, Table B.1.

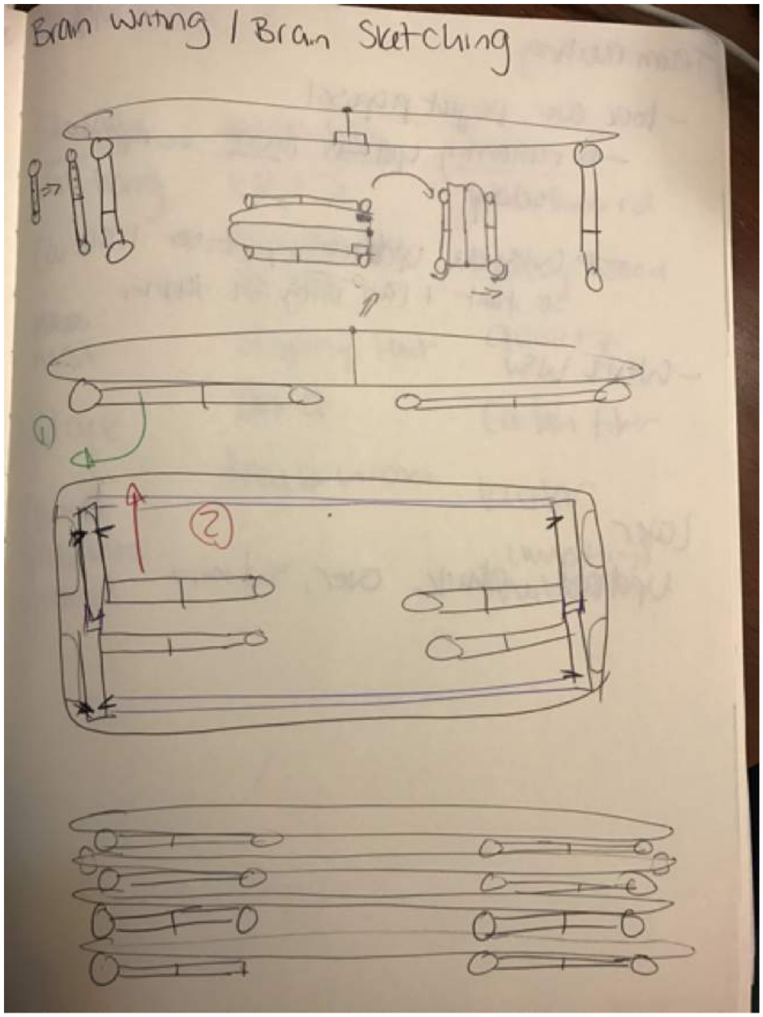


Figure 4.1: Sample image of sketches from brain-writing session.

Another ideation session involved creating a morphological matrix out of the three main design functions of the table: storage, mobility and surface. Storage focused on the particular storage mechanism, which would need to be deployed for a particular design, like nesting, stacking, folding or some other mechanism. Mobility would be the different ways to move the table, such as having it sit on wheels that roll across the floor or having the table's legs have a low coefficient of friction where they can be comfortably dragged. The table's surface refers to both its shape and composition. Potential ways to accomplish these three design functions were listed as seen in Figure 4.2. This figure allowed us to combine ideas in somewhat unusual ways that may not have been thought of before, like the not so feasible solution of having a circular table that rolls across the floor with a surface made of Kevlar that stores in a space that is carved into the ground.

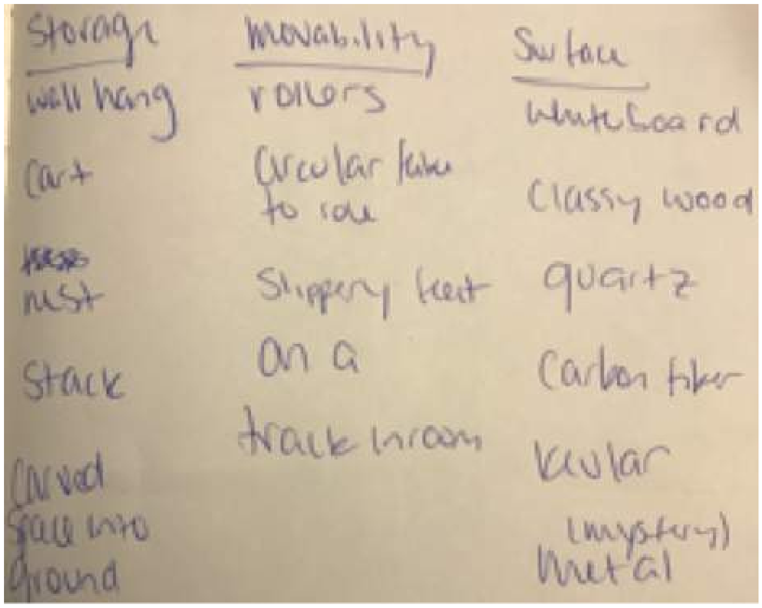


Figure 4.2: Morph Matrix

In the next ideation session, each team member took a space on the whiteboard to draw out their different ideas and contemplate how ideas could be combined. This ideation session also took time to list some of the extra features, which would be ideally incorporated into the table as seen in Figure 4.3. Some of the bonus features would be further considered at a later ideation session. This ideation session generated roughly 20 new ideas, though not all of them were serious contenders for a final design. The individual ideas written on this whiteboard can be found throughout Appendix B, Tables B.1 to B.8.

Figure 4.3: Chaos on the whiteboard

The next ideation session was comprised of each team member continuing to expand on surfaces, surface forms, storage mechanisms, supports, bonus features and other factors, which could be considered in the design process. Each team member had five minutes to fill a half sheet of paper

like the one in Figure 4.4, with their ideas before the sheet was posted to the window, Figure 4.5. During this process, there was no discussion of ideas until the very end of the ideation session when each member presented their rationale for each design listed with an explanation of their sketches. By completing this session, over 50 more sketches were added to our collection of potential design features and full-fledged designs. A closer view of the images found in Figure 4.5 can be found in Appendix B, Table B.1, Table B.2, Table B.3, Table B.6, and Table B.8

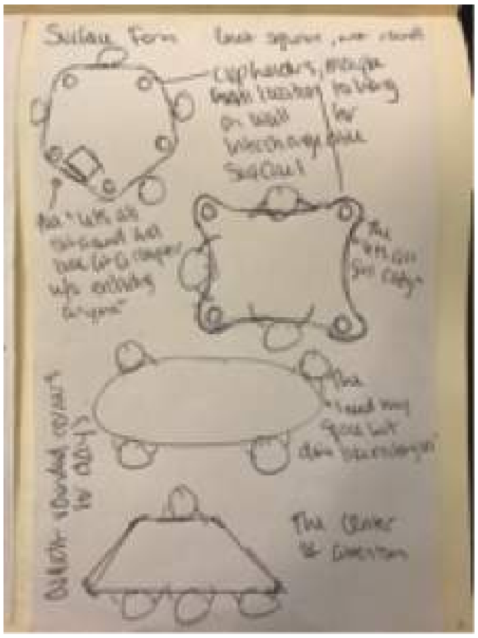


Figure 4.4: Example sheet.

Figure 4.5: Design feature based ideation.

In Figure 4.4, we explored four non-standard table designs. The only rules to this ideation period were that the table could not be a rectangle, a circle or a square. All designs formed on this sheet featured rounded edges to reduce potential injuries from bumping into the side of the table. This example sheet differed from many of the others in that there were descriptions, which accompanied the drawings, to better explain the function of the specific surface form. These individual ideas may be found in Appendix B, Table B.4.

After having generated about 75 designs by this point, each team member took time to expand upon one specific design presented during the previous ideation sessions. Each person was given free range to expand on whatever aspect they saw fit for this design. One example of this is shown in Figure 4.6, where the concept of a center-mounted table, named “The Squid,” was further developed.

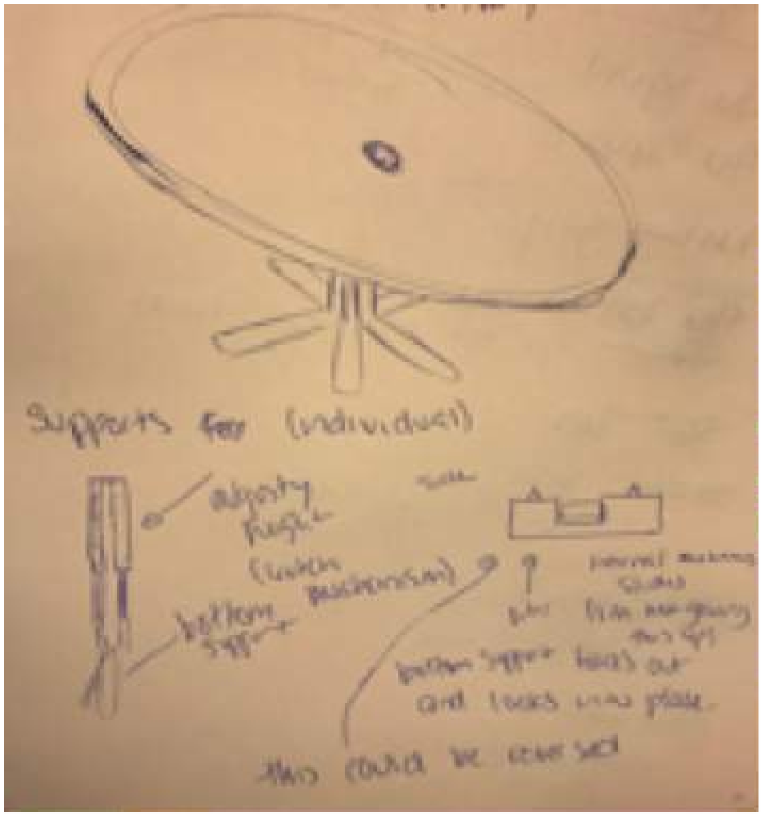


Figure 4.6: Development of a design for “The Squid”.

To avoid having each team member get set on one specific design, another ideation session was held where inhibitions were somewhat lessened. The around 75 sketches produced by this session were primarily conceptual and did not focus on the actual feasibility of the design. The goal of this ideation session was to focus on three key desired “want” items and on three storage mechanisms, as shown in Figure 4.7. The three “want” items were adjustable height, adjustable table angle and an incorporation of outlets, as sketched in Figure 4.8. The three main storage mechanisms for the tables were folding, nesting and stacking. Many of the other ideas proposed on sticky notes can be found throughout Appendix B.

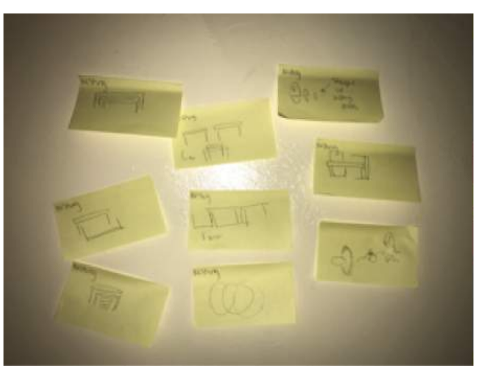


Figure 4.7: Sticky notes on the wall for folding mechanisms.

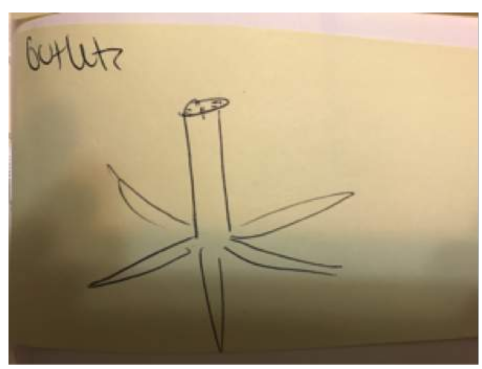


Figure 4.8: Example sticky note for outlet incorporation at the center mounting point of a center-mounted table.

The last ideation session held was a session where we created some of our top design ideas using foam core and basic crafting supplies. Out of the roughly 150 sketches generated over the course of the six prior ideation sessions, six main designs were created during this session. The designs are seen in their multiple configurations in Figure 4.9 through Figure 4.14.

Figure 4.9: Concept modeling of small stacking tables.

Figure 4.10: Concept modeling of a swivel-leg table

Figure 4.11: Concept modeling of “The Squid”

Figure 4.12: Concept modeling of “The Drafter”

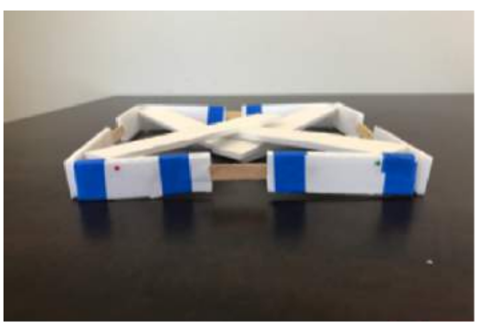


Figure 4.13: Concept modeling of “The Square”

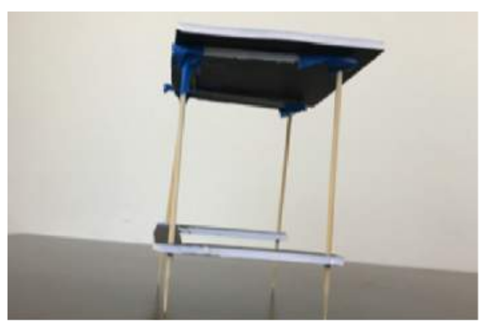


Figure 4.14: Concept modeling of “Nesting Trapezoids”

4.1.1 Example Concept Development

Throughout the ideation process, we came up with several interesting solutions to the problem of having a table that is sturdy, yet portable and stores compactly. Although it is valuable to embrace

the creative process and generate as many ideas as possible to help us expand our possible solutions, not all ideas are feasible, or even physically possible, given the constraints placed on our project. Below are several of the more notable concepts we encountered.

A very simple design for a worktable is a rigid "C" shaped table as shown in Figure 4.15. This design would be easy to manufacture, and relatively straightforward to use, however due to its solid and unchanging nature the ability to store compactly is greatly reduced. This would only allow four tables to be stored within the footprint of one table. Another issue with this design is the fact that one side would be completely blocked off because of the frame. While this would likely not affect standing users, it would cause problems for a team entirely seated on stools.

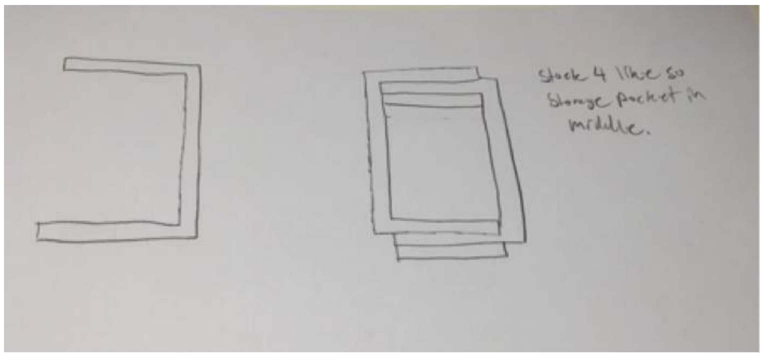


Figure 4.15: C-shaped nesting concept.

Another design we considered was a collapsing table as shown in Figure 4.16. This table would have limited leg interference due to having legs at each of the corners when in fully expanded form, but had some potential stability issues without additional reinforcement. Furthermore, the storage footprint could only be significantly reduced if the tables were stacked in a surface to wheel configuration, which might damage the table's surface or be heavy or awkward to move into a fully stored state. The collapsing method on this table was inspired in part by the portable work table referenced in Figure 2.8.

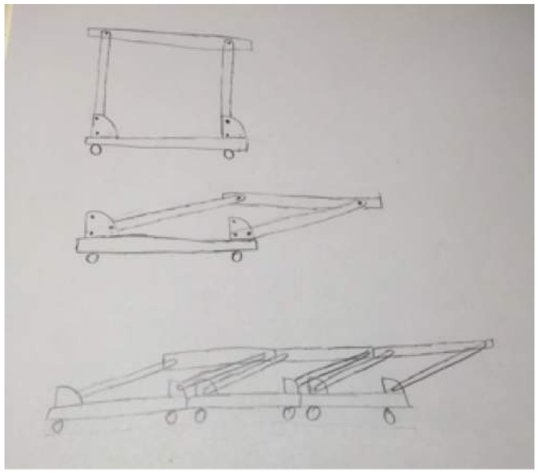


Figure 4.16: Folding Concept. The legs hinge, which allows the table to fold flat almost like a folding chair. Multiple tables can be overlapped for more compact storage.

A very interesting design for compact table storage was inspired by the way shopping carts nest when stored. The design shown in Figure 4.17 has a surface that can flip up and allow angled frames to nest in a compact manner, while allowing for a fairly simple reconfiguration into a usable mode. This design has several issues, including how the surfaces are stored in an elevated, or high-energy form. If whatever support keeping them in place were to fail, it could fall back down on the frame and potentially damage the table or injure a user. Furthermore, care would need to be taken to ensure that the frame section of the table doesn't interfere with stool legs.

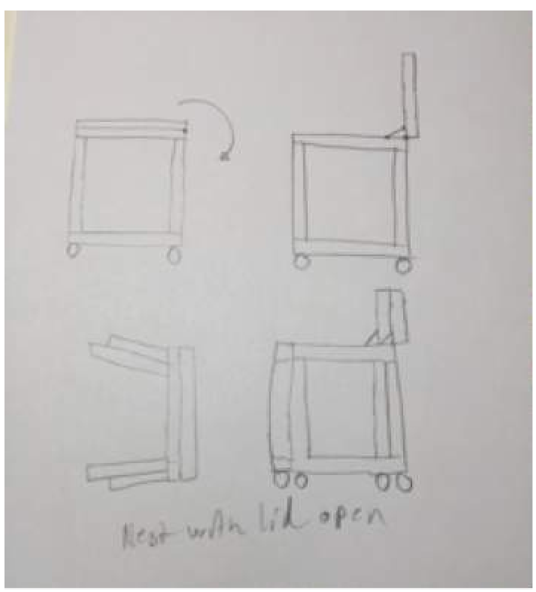


Figure 4.17: Shopping cart nesting concept.

4.2 Top Concept Overview

Out of the top ideas generated throughout the ideation process, three were selected to be created in SolidWorks to perform a quick analysis of basic fits of parts and validate some rough sizing of features of each table. Below are the top three designs in their standing and stored configurations.

4.2.1 The Drafter

The basis of this design is an adjustable height table seen in Figure 4.12. The SolidWorks models can be seen in Figure 4.18 and Figure 4.19, which demonstrate configurations with a flat surface for standard work and an angled surface for drafting, respectively.

Figure 4.18: Flat top.

Figure 4.19: Angled.

4.2.2 The Square

The basis of this design is an expandable base with changeable height legs, which can be adjusted to fit any surface shape as seen in Figure 4.13. The SolidWorks model can be seen in Figure 4.20, which displays the standing and collapsed state of this table, simultaneously. This design is compelling because it is adaptable for nearly any type of surface which may be used with it, since the base is able to expand or collapse based on the size and shape of the table top. The square contains only three distinct major parts at its base design, which makes it easier to manufacture since it is easier to make multiple copies of the same part than it is to make many small parts.

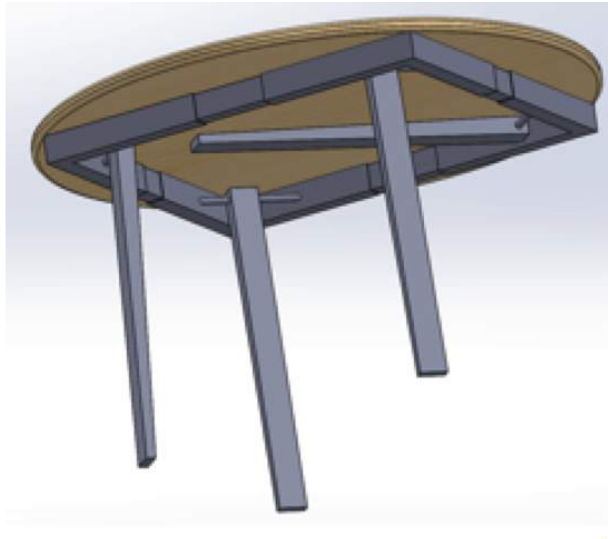


Figure 4.20: The Square table.

4.2.3 Nesting Trapezoids

This design is based on a shopping cart as well as other nesting trapezoids seen in Figure 4.14. The SolidWorks model can be seen in Figure 4.21, which displays the fully assembled form of the table.

Figure 4.21: Individual trapezoid.

4.3 Top Concept Selection

From over a hundred initial concepts, we were able to decide on one main concept through the method outlined below. First we went through each concept and decided whether or not it was feasible either in part or as a whole. Concepts that were totally unrealistic, such as a table that levitated through the use of magnets, were discarded entirely. The realistic parts of unrealistic designs were preserved, such as potentially using the solid C shaped design in Figure 4.15 for stools instead of for the tables themselves. From here, we had a reduced pool of ideas from which we could draw our final choice. Within this reduced pool, there were many concepts that were very similar, which we decided we should refine and combine. This further reduced the number of different concepts we needed to evaluate. At this point, we ended up with the tables shown in Appendix B, Table B.9. We then divided these ideas into categories and chose the best one from each using Pugh matrices. From there, we used weighted decision matrices to more rigorously evaluate our top concepts and move toward a final design.

Table 4.1: Truncated Pugh matrix of storing mechanisms.

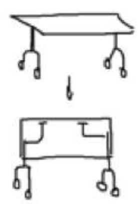
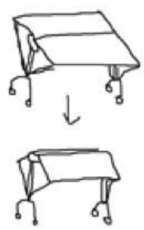
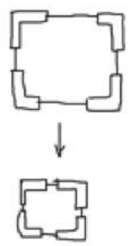
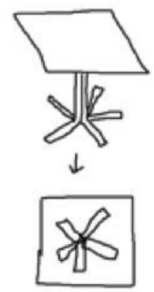
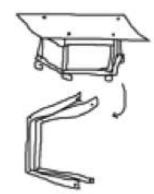
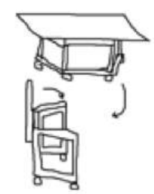
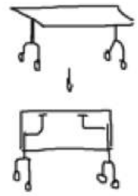
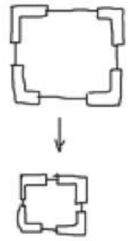
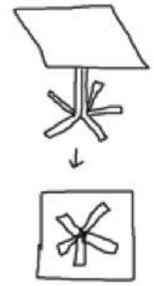
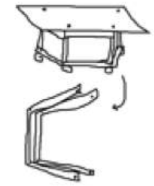
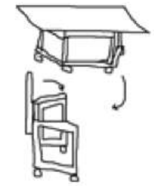
Criteria	 **Baseline (Bonderson 104)**	 **Center Seam**	 **Telescoping Frame**	 **Squid**	 **Frame + Surface Nesting**	 **Nesting with Hinged Surface**
Static Stability	0	1	0	0	1	1
Dynamic Stability	0	1	0	0	0	0
Compactness when stored	0	0	1	1	0	0
Safety	0	0	0	-1	-1	-1
Complexity of reconfiguration	0	0	0	-1	1	1
Physical Ease of Use	0	0	-1	-1	0	0
Height	0	1	1	1	1	1
Aesthetics	0	0	1	1	1	1
Leg Interference	0	0	1	1	1	1
Complexity of Design/Build	0	-1	1	1	-1	-1

Table 4.1: Truncated Pugh matrix of storing mechanisms.

Criteria	 **Baseline (Bonderson 104)**	 **Center Seam**	 **Telescoping Frame**	 **Squid**	 **Frame + Surface Nesting**	 **Nesting with Hinged Surface**
Cost	0	-1	-1	1	0	0
Sum	**0**	**2**	**2**	**2**	**6**	**3**

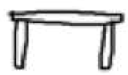
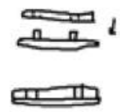
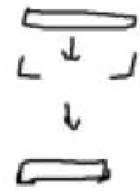
The design we ended up focusing our efforts on was one with a nesting frame and a separate table surface, stored using the method pictured in Figure 26. This particular method scored highly on the compacting method Pugh matrices shown in Appendix C, Table C.1. It appears to be easy to manufacture, allows for compact nesting, incorporates a multitude of possible interchangeable surfaces, and is intuitive to reconfigure. The ease of manufacturing and the intuitive method of reconfiguring both stem from the fact that the overall design is relatively simple in nature. Our current CAD models show that we can compactly nest several table frames, which have a small individual footprint area with the surface removed. Further ideation and calculation will go into a surface storing mechanism, but we hope to come up with a similarly compact design. Finally, due to the fact that this design works based on a removable surface, making several interchangeable surfaces for different uses will take little additional design.

The three main drawbacks to this design are static stability, safety, and the physical ease of reconfiguration. Because the table's surface is separate from the frame, and the surface may only be supported on three sides in our initial design, there are some concerns that the table might not be able to support the full weight of a student on the unsupported side, or the "open" end of the trapezoidal frame. This can be verified via hand calculations regarding the sturdiness of the surface, and mitigated with material selection, table surface reinforcement, or various other means. Safety is another concern, as the separate surface might be heavy and could hurt someone if their hands got caught in the surface-frame interface. This also ties in with the physical ease of reconfiguration. Special care must be taken with this design to make the surface less awkward to handle or easier to reposition for a single user. Other than those three concerns, this particular type of design seems to be the best direction to head in at this point.

Upon selecting this design, we had to consider how the surface would securely attach to the frame. As shown in Table 4.2, after considering several options we decided upon a pin and hole method. The main advantage this has over other techniques is that the surface geometry is no longer constrained by the frame shape. This could allow for a potential rectangular "middle" section if three tables were to be pushed together to form a table with a larger capacity. Furthermore, a pin and hole method should be able to withstand expected shear loads, especially considering that there will be friction between the frame and surface to assist with stability, however more in depth calculations

will be performed to determine specific sizing, including a static analysis to determine what load applied at the edge could apply enough of a moment to cause the surface to "pop off" without additional preventative measures. If this method does not satisfy our calculations, then alternative methods will be considered.

Table 4.2: Pugh Matrix of surface attachment methods

Criteria	 **Perma-nently Affixed**	 **Hinge**	 **Pin and hole**	 **Slot**	 **Groove**
Stability	0	-1	0	0	0
Multiple Surface	0	0	1	1	1
Safety	0	-1	0	0	0
Manufacturability	0	-1	0	-1	0
Reparability	0	0	1	1	1
Intermediate Shapes	0	1	0	0	0
Ease of Use	0	1	0	0	0
Multiple Shapes	0	0	1	0	0
Sum	**0**	**-1**	**3**	**1**	**2**

Based on the Pugh Matrices shown in Table 4.3 and Table 4.4, the materials that the table should be made out of were selected. Since the lead table design of the nesting trapezoidal table with a pin and hole connection allows for multiple table surfaces to be used, more than just the lead options of aluminum and steel may be used as table surfaces, despite the drawbacks of whiteboard and a healable surface seen in Table 4.3. It is likely that aluminum will be chosen over steel and titanium for the support material, due to its better manufacturability and lower cost.

Table 4.3: Pugh Matrix for surface material.

Criteria	**Wood (baseline)**	**Aluminum**	**Steel**	**Healable Surface**	**Plastic**	**Whiteboard**
Stiffness	0	1	1	-1	-1	-1
Sturdiness	0	1	1	1	-1	-1
Safety	0	0	0	0	0	0
Aesthetics	0	0	0	1	-1	1
Durability	0	1	1	1	-1	-1
Manufacturability	0	-1	-1	-1	1	-1
Cost	0	-1	-1	-1	1	-1
Sum	**0**	**1**	**1**	**-2**	**-2**	**-4**

Table 4.4: Pugh Matrix for Support Material

Criteria	**Wood (baseline)**	**Aluminum**	**Steel**	**Stainless Steel**	**Plastic**
Stiffness	0	1	1	1	-1
Sturdiness	0	1	1	1	0
Safety	0	1	1	1	0
Aesthetics	0	1	1	1	0
Durability	0	1	1	1	-1
Manufacturability	0	-1	-1	-1	0
Cost	0	-1	-1	-1	-1
Sum	**0**	**3**	**3**	**3**	**-3**

Two more Pugh matrices were used to evaluate the overall surface shape and the movement mechanism. In Table 4.5, we evaluated nine different table surface shapes to ensure that out final surface shape would be the optimal. From this table, we found that the trapezoidal shape was the best design option. In Table 4.6, we evaluated six different methods of moving the table to determine which method of moving the table was the best option. From this table, we concluded that the walker mechanism was the ideal way to move the table.

Table 4.5: Pugh Matrix for surface shapes.

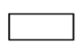
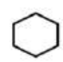
Criteria									
Seats 4	0	0	0	0	1	1	1	0	0
Easy to get in/out	0	0	0	0	0	-1	-1	0	0
Sufficient elbow room	0	0	-1	-1	0	0	0	1	0
Equal presence for all	0	0	0	-1	0	-1	-1	0	1
Aesthetically pleasing	0	0	0	1	-1	-1	-1	1	1
Ease of manufacturing	0	0	-1	-1	-1	-1	-1	-1	-1
Interaction ergonomics	0	0	-1	-1	-1	-1	-1	-1	0
Sum	**0**	**-3**	**-3**	**-1**	**1**	**2**	**?**	**?**	**?**

Table 4.6: Pugh Matrix for movement mechanisms.

Criteria	**Can't Move (baseline)**	**Casters**	**Rollers**	**Sliding**	**Brute Force**	**Walker**
Static Stability	0	-1	-1	-1	-1	-1
Dynamic Stability	0	-1	-1	-1	-1	-1
Safety	0	-1	-1	0	0	0
Aesthetics	0	-1	-1	1	-1	1
Manufacturability	0	1	1	1	-1	1
Cost	0	-1	-1	-1	0	1
Ease of Motion	0	1	1	1	0	1
Sum	**0**	**-3**	**-3**	**-1**	**1**	**2**

Based on the results of our six Pugh matrices, we selected a final design that of a nesting trapezoidal frame made out of steel with a trapezoidal surface made out of steel or aluminum, which attaches to the frame through a pin and hole mechanism. The frame will also use a walker mechanism, indicating that the frame has wheels in the front and stoppers in the back which will allow the table to easily be moved while also being stable when still.

4.4 Satisfying Specifications

Before we continue to focus in on a particular type of solution, we must first verify that our path is taking us in the right direction. If there are some requirements that our design will have difficulty satisfying, then we must either take extra care to make sure we meet those high-risk requirements, verify whether or not the original requirements are necessary, or choose a different design. Some requirements such as height, width, or depth are relatively easy to meet, as we can factor those into our detailed design from the beginning, and they are evaluated with a simple dimension measurement. Other requirements such as ability to compact or store multiple tables within a smaller footprint require a bit more thought to verify.

To ensure that we would be able to store ten tables within the specified storage footprint, we created multiple tables within SolidWorks and measured the overall storage dimension. Ten tables could be comfortably stored in an area of 5 ft by 5.5 ft. Requirements, such as ease of reconfiguration, will guide our process as we continue to move forward with a more detailed design. Because our main design will require the table surface to be lifted and aligned with the frame, we must attempt to reduce the weight of the table surfaces and add some sort of handles to make it as maneuverable as possible. If pegs are used to line up and secure the surface, then we will need to ensure the surface will not "pop off" if leaned on from an edge, and we might want to consider an additional protective surface around the holes to prevent scratches to the surface. The nature of reconfiguration is straightforward, and only requires one step: align surface with frame, so it should take relatively little time to set up. The only time pinch points should be accessible to users is during the configuration process, where location at which the frame meets the surface become a potential pinch point, however extra care can be taken during the design process to mitigate this safety issue by possibly reducing the contact area between the surface and frame, or by moving the frame further from the edge of the table.

Preliminary calculations have been performed and are discussed in the section below. Issues such as tipping, frame buckling and more in depth calculations will be performed as we move forward with material selection and detailed frame layout. Currently, the frame should be able to withstand our target loads; however, as mentioned earlier, the surface may require additional reinforcement at the unsupported side. An initial budget per table has been estimated in the quantitative analysis section below, assuming some rough dimensions and material selection, and may change as we modify our design. Finally, the durability of the table will depend on its daily use, and cannot currently be modeled with great accuracy.

As part of the design process, it is important to perform calculations to ensure that the final product satisfies the engineering specifications. In the case of our table, we needed to be sure that

the table can support the required loads while staying within deflection tolerances and not tipping over. Analyses were performed to help us dimension certain parts of the table and aid in material selection for components. Preliminary hand calculations for some of these elements can be found in Appendix H. Through this quantitative analysis, we are able to more adequately design the frame and surface dimensions, particularly thicknesses, and select the appropriate materials for said items to achieve the desired deflection and loading criteria.

To validate our design, initial hand calculations were done to check tipping, maximum surface size for an equilateral trapezoid, and budget. According to initial calculations shown in Appendix H, Figure H.1, the table will tip if the lateral force exceeds one third of the entire table's weight. This was calculated assuming the table will not slip under these conditions, and assuming that the center of gravity of the table was located closer to the wide side. One third of the weight could be incredibly low, considering that we intend the table to be easily portable, so we must either revise our assumptions and recalculate, or redesign the table to not tip as easily. This instability is caused by a combination of low weight, and a tall table. Calculations performed in Appendix H, Figure H.2, demonstrate two ways that a table surface could be cut out of a standard sheet of Oriented Strand Board (OSB). Based on Orientation 2, we could have equilateral trapezoidal surfaces with a longest side of 27 inches. This determines the maximum surface size we can have for the given geometry while still being efficient in our use of standard materials. An initial cost per table is shown in Appendix H, Figure H.3.

5 Selected Concept

Ultimately the final design we decided to develop was the nesting frames with separate surfaces. This design was selected based on its manufacturability, ease of maintenance, ability to compact with ease and the added benefit of interchangeable surfaces. This design has no moving parts, and consists primarily of a frame and a surface, meaning that it will be much easier to manufacture than more complex designs. Furthermore, because the surface is separate from the frame itself, incorporating multiple types of surfaces can be combined with the frame to create several types of work areas such as a hexagonal space for a team of 6 to work at. Additionally, having a separate surface means that if either the surface or frame is damaged, it can be repaired or replaced at a slightly less expensive price, requiring less labor than if the frame and surface were permanently affixed. Finally, using nesting frames allows for compact storage, much in the way large numbers of shopping carts can be stored in a small area. These features, combined with minimal drawbacks, led us to the conclusion that this design will be the best way to approach designing a table for a collaborative workspace. Depending on the surface attachment method, the surface geometry will not necessarily be dictated by the frame geometry.

Figure 5.1: Initial design model.

Figure 5.2: Nested frames.

After creating this original design concept, we continued to develop the design until it reached its final form, seen in Figure 5.3, which we will discuss in depth throughout the rest of this section.

Figure 5.3: Final design.

5.1 Finalized Concept Overview

The table will have two main components: a frame and a table top. The basic shape of the original frame is much the same as the idea generated for the preliminary design review. As seen in Figure 5.4, the two main components of the table the surface, balloon 1, and the frame, balloon 2, remain.

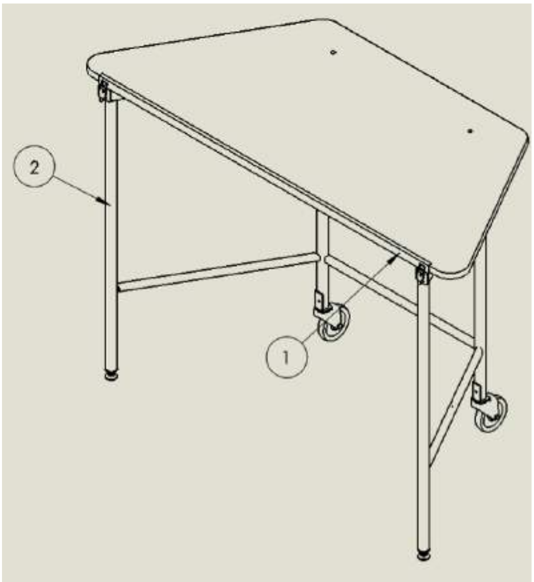


Figure 5.4: Isometric view of the full table model.

Due to the simplicity of the system, we do not require many distinct parts to build this table. On

an overall basis, there are three main assemblies for this design: a frame, a surface and a cart. The total cost for these sub systems is assessed in Table 5.1. These three subsystems were predicted earlier in the Preliminary Design Review.

5.1.1 Frame Overview

The frame will be made out of three different sizes of square steel tubing, as seen in Figure 5.5. The tubing will be cut and welded together and all other components will be purchased and added to the frame to complete the table.

Figure 5.5: Rendered model of the frame.

The bottom bar of the frame may be used as a footrest for those who are sitting while working at the table. This raised bottom bar should also prevent a user from inadvertently placing the legs of a stool over it which could be a potential hazard falling hazard. The combination of mounted casters and back stoppers allow the frame to act as a walker when it is being moved. The user may lift up the back of the table to move the table easily, or have the table rest on all four legs preventing it from slipping while in use. There are also pins and latches located on the table to locate the surface of the table and hold it securely to the frame.

For the exact design specifications and purchased components used, consult Appendix D, Appendix E, Table E.2, and Appendix F.

5.1.2 Surface Overview

The final design will have two different surfaces: one for active design and another for more formal situations. The surface of both table tops will be a large trapezoid, although other shapes of table

tops could be made to fit the table.

The active design surface includes two separate types of surfaces. One side of the table will be painted with a whiteboard paint, which can be used as a whiteboard with dry erase markers. The other side of the table will be made out of Medium Density Fiberboard, henceforth referred to as MDF. In order to increase stability on the unsupported edge of the surface, there will be a metal channel added to increase the rigidity of that side. As another measure to secure the tabletop to the frame, there are reinforced holes in the tabletop, which will be paired with pins in the frame to prevent it from moving laterally. The features discussed can be seen in Figure 5.6.

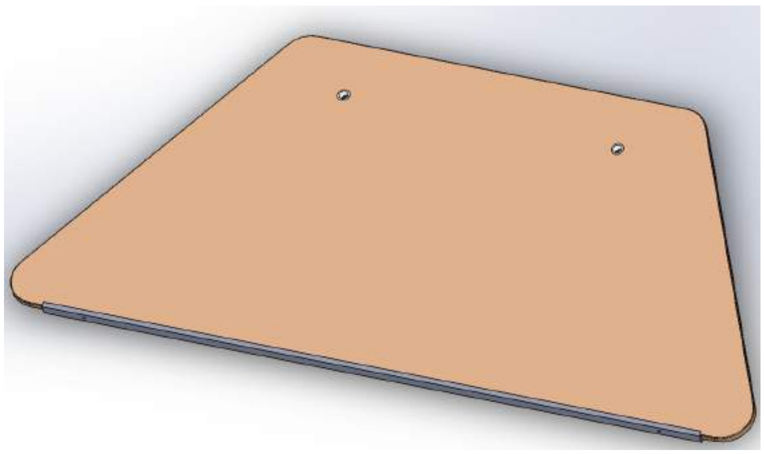


Figure 5.6: Rendered model of the active design surface with the MDF side visible.

The other tabletop will have the same basic shape as the active design surface, being a trapezoid with a steel channel located along on the long side of the table and holes to be paired with pins in the frame. This surface will be made out of Birch Plywood with a sanded border, and to give this table a more professional feel, it will have a varnish applied to it, as seen in Figure 5.7.

Figure 5.7: Rendered model of the formal surface.

For the exact design specifications of both surfaces, consult Appendix D for engineering drawings

and Appendix E for the bill of materials.

5.1.3 Storage Cart Recommendation

In order to easily transport and store the table surfaces, we recommend that a storage cart be purchased to keep the surfaces in a central location. The cart should be used to keep both styles of surfaces organized and upright while the tables are being stored. This cart can also be used to transport the table surfaces as a group, which can reduce setup time and allow the tables to be used in additional rooms.

We recommend that the cart seen in Figure 5.8 is used as a storage cart. Further details about this cart are located in Appendix E, Table E.1, and Appendix D. Because the cart is divided into two storage areas, the active design surface can be placed on one side and the more formal table top could be placed on the other side for organizational purposes.

Figure 5.8: Recommended surface storage cart.

5.2 Materials Selection

Several calculations were performed to determine what materials should be used, including cost, weight, and manufacturability. For the frame: square steel tubing in three different sizes was selected. Multiple sizes of tubing are required to improve the manufacturing process, as angled cuts affect the area available for joining. This is discussed in greater detail under Frame subsystem 5.3. A square cross section makes the joints easier to machine and line up for attaching together to form the frame.

Steel was chosen over aluminum for both strength and manufacturability reasons. Steel has an elastic modulus roughly three times that of aluminum, allowing the use of thinner tubing while still maintaining high structural rigidity. A steel frame should be virtually indestructible under the expected use of the table. After discussing our manufacturing plans with a shop technician, it was recommended that we use welded connections for the assembly of the frame. Welded connections are much easier to make than bolted ones, which require holes drilled through multiple surfaces to line up precisely to avoid any instability in the system. Furthermore, bolted connections require additional care and custom machining when working at non-standard angles. Welding the corners was also recommended over using pipe fittings, because although pipe fittings might be easy to assemble, none exist at the angle we need, and any pipe fitting would elevate the corners above the frame, preventing from any load on the surface from being adequately distributed throughout the frame. Steel is much easier to weld than aluminum, which means that the welded connections will take less time to manufacture, and should have much higher strength than if aluminum was selected for the frame material.

Although steel is heavier than aluminum, a steel frame would still be light enough to be maneuvered with relative ease, especially given that we plan to put wheels on our frame to improve mobility. Additionally, increasing the weight of the frame actually increases the stability of the table, and works to prevent tipping due to loads placed at the edges of the surface.

Another one of the issues with using a steel frame is that it has the potential to rust if left untreated. One of our options for preventing this is by powder coating or simply painting the frames after assembly to prevent degradation and to improve the finish.

For the active design surface, we used medium density fiberboard, or MDF for the core supportive material with a whiteboard coating to allow a user to be able to write on one side of the table while being able to cut and prototype on the other side of the table. MDF is a strong materials that is easy to cut into non-standard shapes like the surface that we have designed. To try to decrease the deflections which may occur to the surface, a steel channel will be added to the long edge of the surface for added rigidity.

For the formal surface, a birch plywood which was selected primarily for its aesthetic appearance and more formal look than the MDF. Again, the long edge of this table will be reinforced with a steel channel for added rigidity.

5.3 Frame

The frame provides the structural basis for our tables. There are three key aspects of the frame, which have been incorporated into the design. First, the frame needs to be structurally robust. This has been achieved by manufacturing the frame out of welded steel tubing as shown by feature 1 in the figure below. Second, the frame needs to be easily moved. We have accounted for this by implementing a walker style mechanism with angle-mounted casters (feature 5) on the front legs and leveling end mounts on the back legs (feature 2). Third, the frame needs to securely fasten to the table surface being used. This is accomplished by setting pins into the frame to locate the

corresponding holes drilled in the table surfaces (feature 3) and by adding magnetic latches to the back of the frame to secure the table tops in place (feature 4). The combination of these features is brought together in Figure 5.9 where we see a labeled drawing of the full frame model.

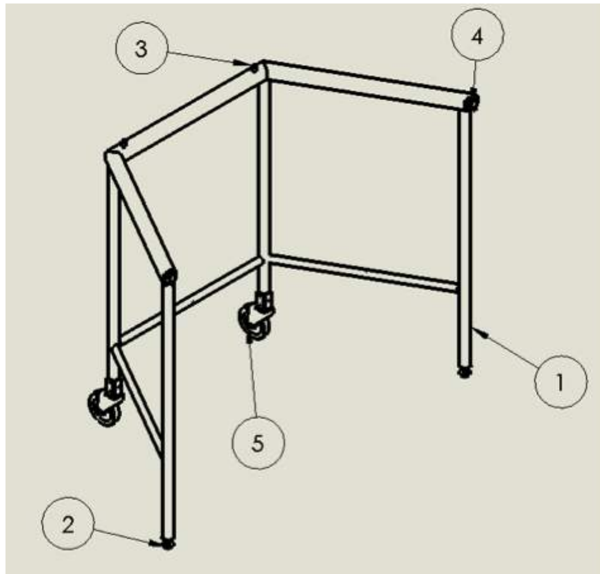


Figure 5.9: Isometric view of the frame with components labeled as follows: 1-Welded Frame Assembly, 2-Leveling End Cap Assembly, 3 - Locating Pins, 4 - Latch Assembly, 5 - Caster Assembly.

5.3.1 Iterations in the Design

To get from the original concept model to the current design, there were seven major fully-fledged designs, which were created in SolidWorks to represent a fully functioning, manufacturable design.

While presenting the initial table design, seen in Figure 5.10, at Preliminary Design Review, we received feedback on the design as to what improvements could be made. First, the lower bar needed to be raised so that it did not create a falling hazard if a student caught their chair over it and leaned back without realizing this. The upper pieces of this model were also designed to be solid bar that was bent into shape, which would not be possible given the resources of the Cal Poly Machine Shops. The upper and lower support pieces were designed with a primary focus on aesthetics and manufacturability as a secondary concern. This design also had a calculated weight of about 60 pounds, which was justified by the use of rollers, which were attached to the bottom of the frame to improve frame mobility, while not requiring users to lift the frame for transportation.

Figure 5.10: PDR frame.

In order to lower the weight of the initial frame, the initial design of the table was simplified and made out of round and square tubing with the bottom support bar removed, as seen in Figure 5.11. Despite being a streamlined version of the original design, this model had a weight of 18.5 pounds. A pin mechanism was still considered the primary method of connecting the frame to the surface at this time.

Figure 5.11: Hollowed tubing design.

In an attempt to reduce the cost of the model and the complexity of material acquisition, this design was recreated entirely out of 1" round tubing, as seen in Figure 5.12. This model had a weight of about 15 pounds but was also the least robust design created so far due to the lack of any additional support mechanisms to ensure the rigidity of the frame. Later designs would build on this basic frame shape but try to make the frame both look and act more robust.

Figure 5.12: Simple piping design.

Concerns that the frame would not be stable enough were raised, and the earlier decision to remove the crossbars to prevent a tripping hazard was brought into question. One solution to this problem was to have large triangular supports, which would support the top and the legs while allowing a user to move their chair underneath the frame to work closely to the table's edge, like what is modeled in Figure 5.13. This idea significantly increased the weight of the frame to a total of 42 pounds, and was not easy to integrate into the existing frame. To lower the weight of the frame, subsequent designs were all based around using piping or tubing.

Figure 5.13: Large triangular supports.

In an attempt to improve the aesthetics of this design, we opted to make a model using round tubing which would eventually be held together by pipe fittings, giving the tables an "industrial chic" styling by incorporating visible industrial components on furniture, as seen in Figure 5.14. This idea was abandoned, however, when pipe fittings made for 120° angles could not be sourced online. Though such pipe fittings could be made as a specialty item, it was likely that the cost to order these would exceed our individual table budget. Furthermore, when consulting with a manufacturing specialist, it was advised that pipe fittings would likely not be made with a tight enough tolerance to stably support the surface.

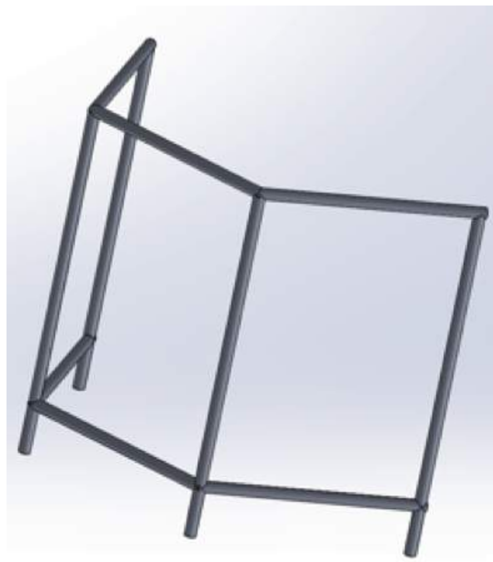


Figure 5.14: Updated model using piping.

As our design moved forward, we decided that the actual frame would likely be constructed using welds. For this reason, the next iteration of the model was based around using steel tubing with 1.5" square tubing for the top support bar and 1" square tubing for the legs and the lower support bars, which can be seen in Figure 5.15. This design includes casters on the front legs and rubber stoppers on the back legs so that the table can be moved around like a walker. However, there were some manufacturability problems with this design, as the tubing in the lower support bars required 90° notches to be cut into their ends, as seen in 5.16. The purpose of these notches was to allow the tubing to fit closely with the legs, which were all positioned square with each other, as seen in 5.17. After discussing the potential difficulty cutting these notches precisely, and the fact that including this complex feature to the design would drastically increase the time and cost to manufacture, the dimensions of the tubing used for the crossbars was changed, removing the need to cut the notch.

Figure 5.15: Original cut tubing assembly with angled cuts on the lower side support tubing.

Figure 5.16: Side support tubing with angled cuts for a fit with the frame.

Figure 5.17: Closer view of the fit of the lower support bar with the legs.

The final model used for the table requires three different sizes of steel tubing in order to achieve the best fits along the angled edges of the table, as seen in Figure 5.18. Now the notched pieces from Figure 5.16 are no longer necessary as a simple 60° cut will allow the lower support bars to fit flush with the legs.

Figure 5.18: Final cut tubing assembly.

5.3.2 Physical Models

A preliminary full-scale prototype was developed with a PVC frame and a foam core surface, seen in Figure 5.19. The primary goal of this model was to get an initial feel for the overall size of the table. While this goal was accomplished, the initial model was not sturdy enough to test the utility of the chosen dimensions.

Figure 5.19: PVC Model.

A secondary model was developed using wood, screws, and hinges, as seen in Figure 5.20. While

this structural prototype was still relatively unstable, it was practical. Work could be performed on its surface, which allowed us to determine which frame and surface geometry would be ideal. After testing with this surface, we decided that a larger surface with 27" sides would be preferable to a smaller one, as two users felt cramped in the original space. Having hinges on the frame also allowed us to determine which angles we wanted to use to maximize stability.

Figure 5.20: Wood frame.

Finally, a third model was constructed using steel tubing, seen in Figure 5.21. This structural model was used to test the weight, strength, and manufacturability of our final design. Starting with steel tubing we went through much of the manufacturing process ourselves to get a feel for the tools available in the campus shops. One of the first problems we encountered along the way was cutting the tubing at the desired angle of 60°. The chop saw in the hangar is limited to 45° angle cuts, so by making a cut at 30° we were able to get the bars close to the correct angle. Unfortunately however, the chop saw was not very precise, and our actual angles were not quite within our tolerances, so additional grinding was performed to finish the job. Shop technicians with more experience should be able to mass-produce tubing cut to the right dimensions. After getting all the tubing to the right size and shape, the next step was welding the frame together. For the upper section of the frame, the three angles pieces of 1.5x1.5x1/8 tubing were clamped, tacked, and welded, before having the top and bottom welds ground flat. Next the legs were welded to the frame, starting at one end of the frame, and then working our way around using previously cut crossbars to verify our location. Due to lack of experience welding frames, the legs were not welded on at perfectly right angles to the frame, meaning that the cross bars no longer fit as intended further away from the upper rail frame. With more welding experience, or some sort of fixture to better square the angles, better results could have been achieved. Finally the cross bars were welded onto the frame. Due to the cross bars being hollow, pressure relief holes were drilled to prevent the welding process from causing a dangerous buildup of pressure within the tubing. Our completed prototype was then able to be evaluated. Due to errors throughout the welding process, the legs of the frame were not even, leading to an overall instability of the frame. The welds themselves however, were able to withstand the at least two students sitting on the frame, confirming our confidence in the welding process as a viable option for joining the frame. Additionally the weight of the frame was 32.2 lbs which was able to be lifted by a single user, however the final design will include wheels to increase mobility.

Figure 5.21: Steel model.

After the third model was created, components were added to the table to enhance the overall usability of the table. Here, the table has been completed so that it reflects the specified design, seen in Figure 5.22. The selection of these components will all be discussed at length in Section 5.3.4. This frame was used to complete testing of this design, which will be discussed at length in Chapter 7.

Figure 5.22: Components added to the initial steel prototype.

5.3.3 Frame Calculation

Before moving forward with the fabrication of a more complete prototype, it is important to verify that the theory behind a product is sound. To that end, calculations were performed to ensure that the material selection, method of joining and geometry of the design were suitable enough to justify the resource investment. Calculations are no substitute for product testing, but they are an important step in the design process that should guide the design away from, or at least alert the design team to potential catastrophic failures down the road.

The main calculations concerning the frame are confirming the legs withstand compressive loading without yielding or buckling, verifying the upper rails do not deflect more than specified under a conservative loading, and confirming that the welds will not fail.

Leg Analysis

Calculations, detailed in Section I.1 of Appendix I, regarding the compressive strength of the legs were performed assuming that a 500 lbf point load would be applied directly above a single leg. With this conservative assumption, the leg was treated as a simple beam in compression, and the results were very reassuring. Due to the high elastic modulus of steel and the relatively low loading, we expect the leg to compress about 0.00137 inches, which is less than 2% of our specified deflection.

Other calculations were performed to verify that the legs would not buckle under our conservative loading, detailed in Section I.2 of Appendix I. The legs were modeled as a column with two fixed ends (due to the welds attaching it to the upper surface and the crossbars), and a conservative length of 36 inches. In reality the leg length will be shorter to allow for wheels and leveling pins to be incorporated in the design without causing the height to exceed our specifications. Legs constructed out of steel would require a loading of 52 thousand pounds before buckling would occur. This is more than 100 times more weight than the most extreme loading conditions we are designing around.

Based on these calculations square steel tubing with one inch sides and a 1/8th inch wall thickness are more than enough to withstand our expected loads.

Rail Analysis

In order to verify the theoretical strength of the upper rail of our frame, we modeled it as a beam supported at both ends with a 500 point load in the middle. The details of this calculation can be found in Section I.3 of Appendix I, but the main conclusions drawn from them are that even under the conservative loading conditions specified (as a 500 lbf point load will likely never be applied to the center of one rail during the frame's use) the maximum deflection at the location of the load was only 0.0220 inches, which is less than 20% of our specified deflection. Steel exceeds our expectations for even the most conservative loading situations.

Joining Methods

Two main joining methods were considered for the square steel tubing selected for the frame: welding and bolting. Ultimately welding was chosen due to requiring less time and precision than drilling holes for bolting, but calculations were performed to verify the structural viability of each method.

For welding we assumed complete penetration of the weld, with a weld area based on the size and thickness of the tubing. In reality we will have a larger weld area based on the thickness of the weld around the outside of the tubing, or by having a wider tube area based on angled cuts of tubing. With our conservative estimate, we calculated that our weld would need an ultimate strength of 484.8psi for an axial load, or 1523.8psi for loading in shear. Both of these numbers are much lower than the expected ultimate strength of the materials we will be using. Details of these calculations can be found in Sections I.4 and I.5 of Appendix I Testing will still be performed to verify that welds will in fact work and that there aren't any critical errors in our calculations, but we have confidence in this joining method.

For the bolt calculations, we assumed a standard sized 1/4in bolt would go all the way through the tubing, and each side of the bolt would bear one half of the total expected loading. Our calculations revealed that the minimum yield strength required for the steel tubing would be 4ksi, while the minimum yield strength required for the bolt would also be 4ksi. Both of these minimum strength requirements could easily be met by steel tubing and standard bolts. Details of these calculations can be found in Section I.6 of Appendix I.

5.3.4 Component Selection

Beyond the basic shape of the frame created out of steel, the functionality of the table is increased by the the addition of five other components: angle mount casters, leveling end caps, locater pins, steel end caps, and magnetic latches. The first two components increase the mobility and stability of the frame. The other three components are required for a better interface between the frame and the surface.

Angle Mount Casters

The angle mount casters were selected to allow the table to be tipped up and rolled around an area with ease. The ability to rotate 360° allows the table to be easily moved about a space when the back two legs are tipped up, so that the table acts as a walker. Due to the width of the frame at 48 inches, it is important that a table is able to be turned so that it fits through small spaces without requiring the user to exert much effort. The casters selected, detailed in Figures D.5 and D.6, were selected due to their strength and ease of attachment to the legs of the table which can be seen in Figure 5.23. Although these casters are expensive at $21.00 each, we assume that they are well manufactured and will fulfill the duties required as a component of this table.

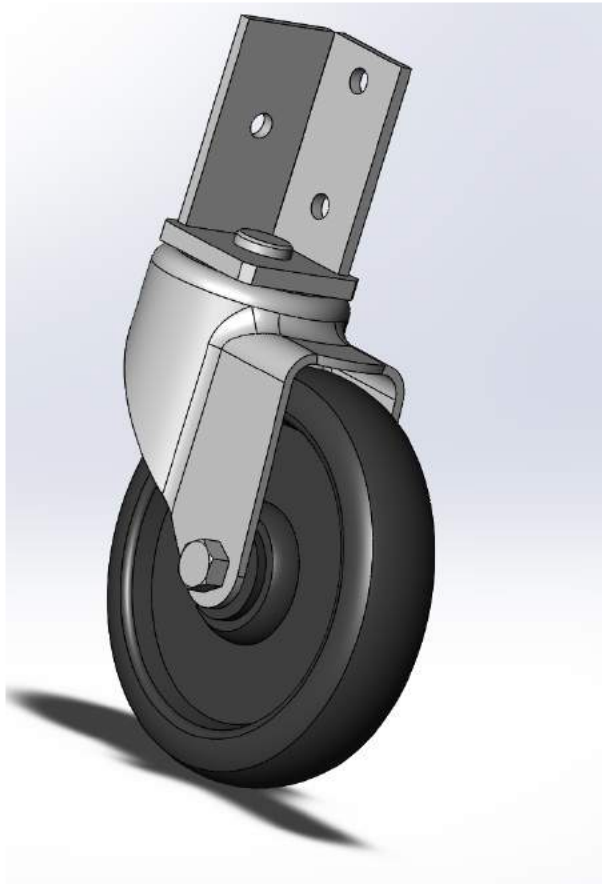


Figure 5.23: Solidworks model of the selected caster.

These casters were the strongest available in a reasonable size. Though they are only rated for 110 lb each and the overall loads required of the table were chosen to be 500 lb over the whole table, we assume that the casters will be able to support the 125 lb load which will be placed on them, despite not being rated for such loads. To validate this assumption, we will test the full prototype of the table to discover how the casters respond to such loading.

The ease of mounting the casters onto the table was also of great importance when choosing casters. The bracket on the side of the caster allows the caster to be attached to the leg of the table with a three screws placed through holes drilled into the side of the table. This is a faster process than welding the casters onto the table or having to create fixturing to attach a plate caster to the table.

Leveling End Cap

Next, the leveling end caps were chosen to accommodate the legs of the table not being the same length and to accommodate the ground that the table is being used on not being perfectly level. To do this, the leveling end caps seen in Figure 5.24 were selected. These caps are relatively inexpensive, at a price of $13.00 for four, which then can be used for two frames.

Figure 5.24: Vendor image of the end caps.

These caps are made to fit into the 1 inch square tubing which is used on the table. The main portion of these caps are made out of plastic so that they can be pressed into the tubing and have ridging to create the friction required to keep the caps in the frame. The threads in the caps allow the table to be moved up and down around 1/2 inch to properly level the table.

Locater Pins

Locater pins are necessary to keep the surface in the desired location while in use. The pins ensure that the table will be kept in the same general location at all times without sliding around. Initially, 1.75 inch long, half inch diameter dowel pins were selected to sit in the holes but to save cost, these were then changed out for a half inch diameter steel rod cut to length for added cost savings.

Steel End Caps

Steel end caps are required to have an enclosed surface for the top portion of the table. The steel end caps enclose the surface and allow for the magnetic latches to be easily attached to the back end of the table as seen in Figure 5.25.

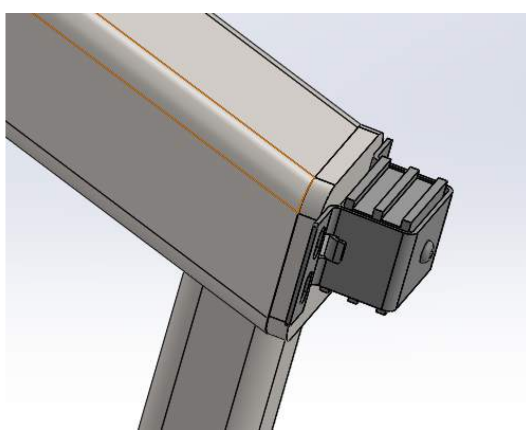


Figure 5.25: Solidworks model of the magnetic latch attachment to the end cap.

Magnetic Latches

Instead of using traditional latches, with a draw and a strike, magnetic latches were selected to allow the surface to be easily flipped over, thus allowing both sides of the surface to be used easily. Magnetic latches allow for some variability in the manufacturing of the table tops.

These latches were also chosen for their strength, or lack thereof. These latches have a rated strength of 13 pounds which on the low end of the possible magnetic latch strengths. A weaker latch was chosen specifically to create a hierarchy of failure of the table surface. This means that the surface of the table is likely to first pop off of the latches before the surface would tip which would occur before the surface would collapse.

5.4 Surfaces

There are two surfaces made for each frame: a work surface and a formal surface. The work surface is intended to be used in an active design setting where one side could be used to sketching ideas with a white board coating on one side and the other side could be used to make rough prototypes on without worry of damaging the surface (feature 2), as seen in Figure 5.26. The formal surface is meant to be used at most other times, for example during a classroom situation where the need to prototype is not a direct concern or during a time when the space needs to be used for more formal occasions like networking sessions, like the surface seen in Figure 5.27, feature 2. These two surfaces attach to the frame with holes that have a PVC sleeve which protected them from the fit with the pins on the frame and latches to create a secure full table (feature 3). Both surfaces have a steel channel which will act as an attachment mechanism for the surface to the back latches located on the frame.

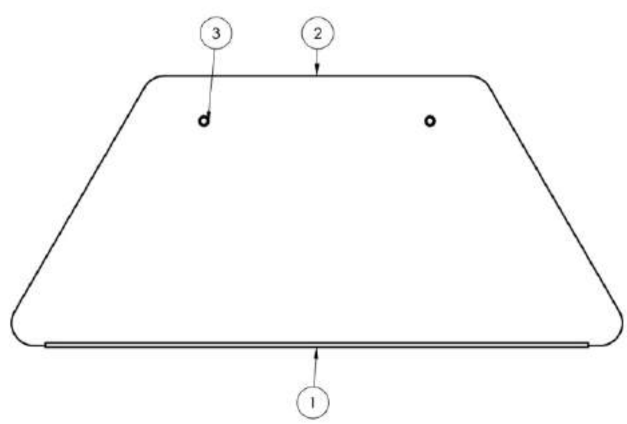


Figure 5.26: Isometric views of the work surface with components labeled as follows: 1-Channel Support, 2-MDF Surface, 3-PVC Sleeve

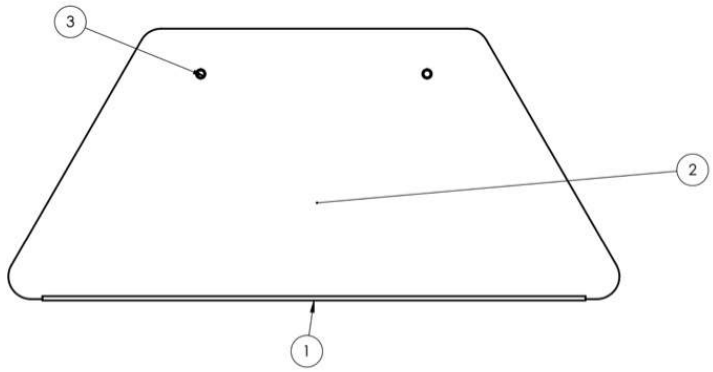


Figure 5.27: Isometric views of the work surface with components labeled as follows: 1-Channel Support, 2-Birch Plywood Surface, 3-PVC Sleeve

5.4.1 Iterations in Surface Design

Originally our surface was a trapezoid with three sides that were 24 inches long, and a long side of 48 inches long. After getting a feel for the size of this work area we determined that a larger surface would be necessary to allow users to not feel cramped when working in groups with three or more students. The dimensions of the surface were then increased to 27 inches on three sides with a long side at 54 inches which is maximizes the size and number of table surfaces which can be cut out of a standard sheet of wood. Ideally we would be able to have an even larger surface, however concerns with table stability, and using the standard wood sizes efficiently limited our size.

Other major design changes included reducing the thickness of the surface. Originally we had an unreinforced surface, which required a thickness of 1.5 inches to avoid excessive deflection on the unsupported side. To reduce the thickness of the surface, we added a metal supporting channel to the long side of the table. This channel has the dual purpose of both preventing deflection, and providing a location for strikes to be added. By acting as something for the latch to attach to, we were able to prevent pop off, and improve the stability of the overall table.

Based on the desire to have a working surface with a white board finish on one side and a cutting surface on the other side, we designed a surface, which would be made out of shower board and oriented strand board. Shower board acts as the white board surface while the OSB acts as a strong cutting surface. These two pieces would then be bonded together with a slot routed into the side where a rubber edging could be installed to make it appear as though there is a seamless edge between the two surfaces.

After a review of this design and many comments on the feasibility of bonding a shower board surface to the OSB as well as the difficulties of routing OSB, we decided to make a change to our

material selection. For a similar price to the OSB, we can purchase Medium Density Fiber Board (MDF), which has a flat surface that should easily bond to the shower board. In addition to this, MDF is also easy to rout.

Another comment made at the design review was that the holes drilled into the surface could get damaged with normal use, causing the table to be less secure over time. We addressed this issue by sourcing and implementing drill bushings which will act as spacers between the pins and the holes drilled into the table. These drill bushings have been selected to have a clearance fit with the pins so that the pins will not get jammed into the holes. The bushings selected will have an interference fit with the surface itself, requiring them to be press fit into place, which will ensure their position and security in the surface.

Due to the lack of durability of showerboard, it was decided that a whiteboard paint should be used on one side of the surface instead of bonding showerboard to MDF. Since the whiteboard surface is going show scratches and wear faster than any other part of the table it was decided that the showerboard was not a key feature and could thus be replaced by paint which also works to reduce the overall width of the surface.

5.4.2 Physical Model Discussion

Our inital surface physical models consisted of different sizes and shapes cut from a standard sheet of 5/8 inch thick OSB. We cut three shapes out of a single sheet of OSB. The first shape was a trapezoid with three equal sides of 24 inches, and a long side of 48 inches. This matches the dimensions of our current iteration of the frame. The second surface was a 3 foot by 4 foot rectangle, which served as both a maximum size check, and as a surface that could be cut down for future models. The third and final surface is a 3 foot by three foot square, which was an attempt to evaluate alternative geometry. This model ended up not being wide enough to fit our current frame, and has been set aside.

Although these models gave us an initial estimate to the weight and rigidity of the work surface we intend to build for our table, more prototyping must be done to evaluate different materials, as well as the composite manufacturing method.

Another surface was made out of MDF, seen in Figure 5.28, and was used for testing purposes of the table as a whole. This model was cut to shape on the table saw and the corners were sanded into radii before the steel channel was attached to the long edge of the table. There are no bushing supports in the front holes of the surface so this surface needs to be forced onto the frame to remain in place. Through use in testing, the holes of the frame did widen, thus justifying our desire to reinforce the holes on future models.

Figure 5.28: Prototype surface to be used with the prototype frame to be used for testing.

5.4.3 Surface Calculations

There were several main calculations that were directly related to the surface subsystem. Aside from the structural analysis of the surface itself, overall stability calculations for the table (including tipping and pop-off) are directly determined by surface geometry.

Surface Strength

Preliminary calculations were performed modeling the active surface as a centrally loaded beam as detailed in Section I.7 of Appendix I. Other assumptions include a line load of 500 lb, and that the shower board part of the composite would not contribute to the bearing of the load. These calculations are a crude representation of the physical situation, and more advanced modeling techniques will ideally be used as me move forward with the design. The unsupported active work surface is not able to withstand our conservative loading without deflecting about 13.1 inches. To remedy this a supporting channel was added to the back of the surface, however, the currently specified support channel actually deflects more than the surface itself does at 13.67 inches of deflection under our conservative loading. Due to the extremely crude and conservative nature of our model, further analysis and testing was performed before a the surface can be guaranteed to meet our specifications.

Further analysis included a FEA model to determine the effect of a 200 lb point load on the back surface. The model of this is seen in Figure 5.29 and predicts a deformation of nearly 4 inches from this loading. To confirm whether or not this will occur, testing of a physical model was conducted.

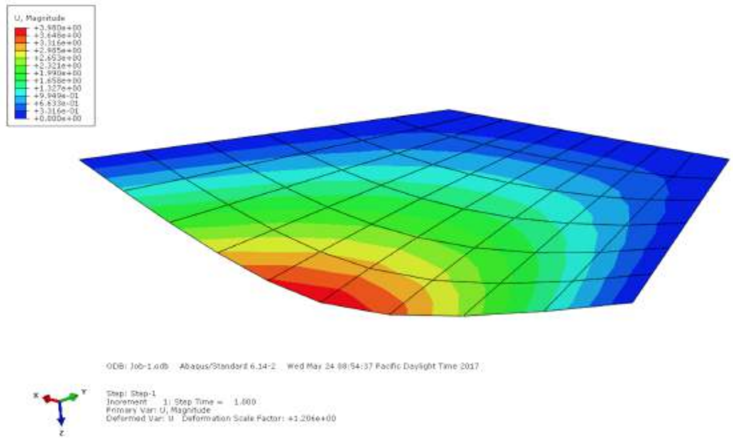


Figure 5.29: Deflections predicted by FEA model of a point loading at the center of the back surface.

Table Stability

It was important to verify that our design will lead to the construction of a stable work surface. To that end we must verify that the table will not tip under the expected loading. Tipping calculations were performed by summing the moments around the front wheels of the frame. Centers of gravity and component weights were estimated using Solidworks, and an external load was assumed to be applied at the edge of the surface, which extends three inches past the edge of the frame. Under these conditions it is predicted that the table will tip under an applied load of 138.6 lbs as detailed in Section I.8 of Appendix I. Modifications will need to be made to future designs to ensure that tipping does not occur as such a low loading, because our current design does not meet our engineering specifications. Potential solutions to this include moving the center of gravity of the frame and/or surface, increasing the weight of the frame and/or surface, or reducing the overhang at the edge of the table.

In addition to tipping calculations, we determined what loading would cause the surface of the table to pop off. “Pop-off”, for the purposes of our project, is defined as the situation in which the loading on one side of the surface creates a moment large enough that the opposite side of the surface lifts up or “pops off” of the frame. Initially the weight of the surface was the only thing counteracting an external moment, however as shown in Section I.9 and I.10 of Appendix I, the surface would pop off under a loading of just 50lbs. After a redesign, latches were added with a rating of 60lbs each, which increased the force to cause pop off to 850lbs, which exceeds our specifications. Under the current design, the table should tip over well before the surface pops off.

5.4.4 Surface Component Selection

In order to have the surface best fulfill the design requirements, components have been selected to create a surface that is durable and cost-effective to manufacture. In order to accomplish this, two components are shared between the two designs: the steel support channel along the long edge of the surface and the reinforcement of the holes.

Wood Selection

Two different types of wood have been selected for the two different applications of the table. For the Active Design Surface, 1/2" MDF was selected due to its durability an its generally flat surface. For the Formal Surface, 1/2" birch plywood was selected for its aesthetics.

The MDF used on the Active Design Surface will be cut to shape before being sanded down. MDF is a very easy to work with surface so it can be easily shaped into the desired form. In addition to this, MDF is a consistently flat surface which allows for one side of the table to be coated with a whiteboard paint with ease. Unfortunately, MDF is a very dense material which causes the surface to be very heavy which can make it hard to maneuver the table into position on the frame. MDF is durable and can withstand scratches which could occur during prototyping.

The birch plywood used on the Formal Surface was chosen because of the grain that can be seen on the top and bottom surfaces of the wood. In addition to this, the stacking of the sheets of the wood which make up the plywood make for another aesthetically pleasing feature.

Coating Selection

For the Active Design Surface, one side will be coated with a whiteboard paint which will allow users to be able to do draw on one side of the table, then flip the surface over to actually cut and build designs based on ideation that was drawn on the other side in whiteboard marker. Rust-Oleum Specialty White Gloss Dry Erase Kit will be used to create the whiteboard finish.

For the Formal Surface, a glossy finish is highly desired. To achieve this, the full surface will be coated in Minwax Semi-Gloss Water Based Oil-Modified Polyurethane. This will give the table a shiny finish while also sealing in the edges of the table.

Steel Channel

A four foot, 3/4" steel channel is used to reinforce the back edge of the table, which is unsupported by the frame. This steel channel is necessary to add additional strength to this edge so that that table can support higher loads as well as increase its durability. The 3/4" channel size fits perfectly along the edge of the 1/2" wood which is used for the surfaces. Since steel is magnetic, the channel

itself is the only required element to attach the back surface of the table to the magnets, allowing the table to be fully reversible.

Hole Reinforcements

The holes near the front edge of each surface have been reinforced with 1/2” PVC pipe cut to the width of the table. PVC pipe has been chosen due to its low cost and its ease of working with. Since the pins will likely wear down the surface over time without the pins, these reinforcements are necessary to keep the holes functioning properly.

5.5 Cost Analysis

Throughout the design process, many considerations have been taken to try to minimize the costs of the table via materials selection and proper sourcing of components to try to make the table as economical as possible.

Since this design process focused mainly on the ability to iterate the design before coming to a final conclusion, we can see that the overall amount spent to reach a final design is much higher than the amount required to manufacture an individual table. The total breakdown of purchases for this project can be found in Appendix G. This cost analysis will focus mainly on the cost to manufacture future tables, not on the overall spending which has occurred as a result of this project.

5.5.1 Individual Assembly Costs

The overall cost breakdown for each assembly of this project can be found in Table 5.1 and found reiterated in Table E.1. This section seeks to highlight the main costs which occur in each major assembly of this design with reference to the attempts that have been made to minimize costs to allow for the tables to be manufactured with without placing stress on those manufacturing them to work too quickly.

Table 5.1: Assembly level bill of materials.

Assembly	**Component**	**Quantity**	**Total Cost**
1000	Full Table	1	$148.28*
2000	Frame	1	$114.27
3000	Active Design Surface	1	$61.74**
4000	Formal Surface	1	$74.31**
5000	Cart	1	$314.33

*Note: This cost accounts for the individual prototyping of one table with one frame and two surfaces, without consideration being made for the cost to manufacture the tables.

**Note: The amount of materials purchased may be used to make surfaces for four tables with limited extra expense.

For a breakdown of the parts being used in each assembly in this system, consult Appendix E for the full bill of materials and Appendix F for detailed part sourcing.

Frame Costs

The most expensive assembly within this design was the frame at $114.27. Steel costs alone are $44.36, assuming that no extra material was purchased in the event of cuts not being made properly. Next, the selected casters run $21.00 a piece. The frame itself will be made welded together which was the most timely manufacturing process for this entire design. Because of this, a fair amount of time to manufacture the table should be factored into the overall manufacturing costs since there is little savings as more frames are made.

The bill of materials for the frame can be found in Table E.2.

Active Design Surface Costs

The active design surface was made from a full 8x4' sheet of MDF with other attachments with a total cost of $61.74 for four surfaces which makes an individual surface cost of $15.43. For its size, MDF was relatively inexpensive at $24.97 a sheet. Costs for this surface become minimized as more surfaces were made from each sheet to reduce wasts. So the cost of the MDF decreases to $6.24 per each surface, assuming that four surfaces are being made out of the sheet so that it was used in its most optimal manner.

Like how the cost of the surface decreased with the wood being cut efficiently, the cost of the other components of the active design surface also decrease as more were manufactured. The steel channel which is used to support the back edge of the table runs $15 for a 20 foot length of channel, when cut to its 4 foot size, it only cost $3 per table. The same goes for the whiteboard paint which is used on one surface of the table. An individual can costs $19.97 but it can be used for four surfaces.

There was very little time required to manufacture the surface as it only requires to be cut to its basic shape, which can be done with a skill saw or a table saw, and then sanded down along the corners with holes then drilled so that the surface can be located onto pins. These were not timely operations and can be completed quickly by someone with limited experience in the shop. Additional time was required as it took multiple coats of paint to cover the surface of the table and there was a 20 minute dry time between coats.

The bill of materials for the active design surface can be found in Table E.3.

Formal Surface Costs

Like with the active design surface, the formal surface's costs decreased as the sheet of birch plywood is utilized to its full potential. It cost $74.31 to manufacture four surfaces which comes down to an individual surface cost of $18.58. Also like the active design surface, the largest cost was the wood which runs $39.95.

The overall manufacturing process was very similar to that for the active design surfaces. The only difference here was that the birch is harder than MDF so it takes slightly longer to sand. In addition to this, the varnish required a two hour dry time between coats which will require techs to frequently attend to varnishing the surface when they manufacture future surfaces.

The bill of materials for the formal surface can be found in Table E.4.

5.5.2 Full Table Cost

Excluding the cost of manufacturing, it cost roughly $250.32 to construct a single, one-off table. Given the $250 budget for an individual table, this budget only allows for no manufacturing time. However, this cost decreases as more tables are made so that it will only cost $148.28 for every four tables made, allowing for over 9.5 hours of manufacturing time, at the rookie shop tech rate of $10.50 an hour, to come in at the $250 budget per table. As each table surface does not require full 8'x4' sheets of wood to create their shape, the initial cost put into creating each table surface will decrease significantly, as demonstrated in Table 5.2.

Table 5.2: Individual table cost with increasing surfaces made out of each sheet of wood.

Number of Surfaces per Wood Sheet	Cost per Table	Hours of Shop Tech Labor
1	$250.32	-0.03
2	$182.29	6.45
3	$158.62	8.61
4	$148.28	9.69

*Note that because one sheet of material is expected to make multiple surfaces, the main cost of additional tables comes from individual components (such as latches and wheels), from frame material, and from labor costs.

The breakdown for the individual cost for each frame can be found in the bill of materials in Table E.2 of Appendix E. In these calculations, the cost to powder coat the frames has not been taken into consideration. This would increase the individual cost of the frames, thus reducing the overall amount of hours that techs would be able to spend working on manufacturing the tables.

6 Manufacturing

The fabrication and assembly of the frame and the surfaces of the table can be done entirely in house. Materials have been selected so that the tables should be able to be easily reproduced on a more major scale. This ability in the future for quick manufacturing will delivery a product in a timely fashion.

6.1 Frame Manufacturing

Since the majority of the frame is made out of square steel tubing, the first step in fabricating the table frame is to cut the tubing to size according to the lengths given in Drawing 211 Appendix D. After this, the ends should be cut at angles and holes should be drilled as also specified in Drawing 211 in Appendix 211. Once this is completed, the pieces should be welded together using a MIG welder according to the welding specifications given in Drawing 210 Appendix D. Then the pins will be inserted, and welded securely into the holes on the top of the frame.

After the basic shape of the frame has been welded together, the frames should be taken to be powder coated by Central Coast Powder Coating in accordance with Appendix F. Once the powder coating is complete, attach the wheels to the front legs of the frame, and attach the base of the latch to the top of the back legs of the frame. All of this should be done at the locations specified in Drawing 200 Appendix D.

6.2 Active Design Surface Manufacturing

To create the active design surface, or the surface more geared towards having projects or craft work performed on it will have two usable sides on the same MDF surface, cut to the dimensions specified in Drawing 310 of Appendix D with holes drilled in the given locations and all edges sanded to round corners. Next, the extra components must be cut to size, according to the dimensions from Drawing 320. Next the one side will be painted with white board paint, specified in Drawing 330. Last, all components must be attached as specified in Drawing 300.

6.3 Formal Surface Manufacturing

Manufacturing the formal surface will be roughly the same process as manufacturing the active surface. The only difference here is that the full surface needs to be coated with the lacquer, specified in Drawing 420 instead of having one side painted with white board paint.

6.4 Maintenance and Repair

Due to how robust this system is, regular maintenance should not be required. Damage to the surface will either require no repair work, or that surface be replaced depending on the severity of the damage. If additional surfaces already exist, than simply replacing a damaged surface with a new one will be an immediate fix to the problem, which can allow more replacement surfaces to be created without reducing the utility of the table.

Damage to the frame could result in either repairs or replacement of the frame. If one of the welded joints fails, then the edges will need to be ground clean and re-welded to make the table usable again. Additionally a protective coating will need to be applied to any exposed steel to prevent corrosion. Powder coating the entire frame for a few small areas is unfeasible, so a repair coating will need to be purchased and applied as needed.

6.5 Safety Overview

Our project has few inherent hazards according to the Design Hazard Checklist (Appendix J). The main concerns for the collaborative work table are pinch points (particularly between the surface and the frame), objects falling under gravity (specifically the surface, which could fall if improperly secured), and the product being used in an unsafe manner (if students decide to stand on the table, or otherwise use it improperly).

First, we would like to address the matter of possible pinch points on the table. Pinch points will likely occur at the interface between the surface and the frame. When users place the surface onto the frame, it is possible that fingers could be caught between the tabletop and the frame. To minimize the likelihood of this happening, we will attempt two techniques: minimizing the interface area and locating the interface far from hand holds when possible. By reducing the interface area, we reduce the area in which fingers could get caught. This can be done by reducing the frame size, as the interface area is dependent on the area that the surface rests on the frame. Reducing the frame's size also has the added benefit of moving the interface away from the edges of the surface, where the user's hands will likely be located. As users maneuver the surface into position, the most readily accessible handholds will be the edges of the surface, so moving the interface towards the interior area of the surface reduces the chance that a user's hand/fingers will be pinched. A trade off of this reduced frame size is that it will reduce the stability of the system. With a smaller support base, the frame itself will be more likely to tip, and as the moment arm between the edge

of the table and the frame has been increased, the surface will be more likely to pop off without additional considerations.

The second concern of objects falling under gravity mainly deals with the surface of the table, which could either fall off of the frame if improperly secured, or could be dropped by the user as it is being moved into position. One way of mitigating this danger is by reducing the weight of the surface, so it is less likely to cause injury if it does fall. While this makes it easier to move the surface, it reduces the stability, as the surface's weight is one of the main counteracting forces to pop off without additional restraints (See Appendix I on the moments involved in pop off). A current estimate of the surface's weight is roughly 10 pounds for the formal surface and 20 pounds for the active design surface, which could cause minor injury, but is far from causing major damage to most users. Another concern with reducing the weight of the surface is that it will likely reduce the load that the surface will be able to bear before yielding. Another potential solution would be to integrate some sort of hand hold into the surface, which would make it easier for the user to firmly grip the surface, and reduce the chances that the surface is dropped. This could affect the usability of the surface, as there might be hand holes or divots in the work surface which could frustrate users.

Finally, the table could be used in an unsafe manner. It is impossible to predict every possible attempt at misuse, but it can be assumed that some users might attempt to climb onto/stand on the table's frame or surface in order to improve their visibility or elevate their presence. Although the table is designed to withstand the weight of a user on the surface, it is hard to predict the location of such a load. It is also possible that any loads caused by a student misusing the table could include greater accelerations or even impact forces that were not considered when originally calculated. In order to prevent injuries caused by the misuse of the worktable, we will attempt to discourage the user from using the table in unexpected ways. This can be done in several ways, including warning labels, or making the table feel less stable. While we want the table to be stable enough to be used in a productive work environment, if it is slightly less stable, students will have less confidence in the table as a standing or sitting platform.

Although there are some minor hazards in our current iteration of the collaborative workspace, we are doing our best to account for and reduce them as we work our way towards manufacturing a final product.

7 Design Testing

While many of the specifications for the table can be measured to determine whether or not they meet the design criteria (like size and weight) which is done in Appendix L, other specifications must tested specifically to determine whether or not they meet our requirements.

Since this table will be used in a classroom environment, tests for this table will emulate the stresses and loads that a table will experience within a classroom setting. The main requirements which require testing are set up time and loading.

Step by step test instructions for all test procedures can be found in Appendix M and the tabulated test results can be found in N for the tests where they are applicable.

7.1 Surface Tests

The main concerns for the surface were the manufacturability, the specifications meeting expectations and its overall strength. To check these parameters requires the following tests:

- Channel Fit Test
- Bushing Security Test
- Corner Rounding Test
- Routing Test
- Surface Weight Test
- White Board Durability Test

Detailed instructions of all tests can be found in Appendix M.1.

7.2 Frame Tests

The main concerns for the frame were the manufacturability, the specifications meeting expectations and its overall strength. To check these parameters requires the following tests:

- Belligerent User Testing
- Pin Insertion and Security Test
- Mobility Test
- Load Wish-boning Test
- Nesting Test
- Un-Nesting Test
- Frame Weight Test

Detailed instructions of all tests can be found in Appendix M.2

7.3 Overall Tests

The main concerns for the overall surface were the its overall strength and durability and the interface between the surface and the frame. To check these parameters requires the following tests:

- 500 lb Distributed Loading Test
- 200 lb Point Loading Test
- Shake Test
- Human Loading Test
- Set Up and Take Down Tests
- Wheel Mobility Test
- Durability Test
- Surface Removal Test

In this section outlines the most critical, and technically difficult testing which must occur as a part of this project. Other system level tests can be found in Appendix M.3.

7.3.1 Set Up Test

For the set up tests, students of different heights will be brought in and timed to see how long it takes for them to set up the table without instruction as to how the table should be properly set up. This test took place three times for each student to get an average set up time for the student population.

Given that future students will likely not read an instruction guide for proper assembly of the table, it is important that the table is intuitive to set up and take down. The multiple trials act as a way to model how students would become familiar with a proper method to set up and take down the table, thus allowing for faster set up and take down times the more times that they use the table.

All times taken from this test will be recorded. Data for this experiment will be recorded in the template given in Table N.1 of Appendix N. To achieve the design criteria, the maximum time to set up the table should be 60 seconds, thus the average time should fall far below this time.

7.3.2 Vertical Loading

There are three vertical loading tests, which took place for this table, the corner point loading of 200 pounds and a distributed loading of 500 pounds. These two loadings were meant to represent one individual leaning onto one corner of the table and a group of people sitting on top of the table, respectively. Since deflections are an intuitive indicator of the table's stability, the deflection of the surface was be measured in these tests, as well as the qualitative feel of the table under these loads.

To perform a test of a point load of 200 pounds, a clamp with a hook will was attached to one of the front corners of the table and increasing amounts of weights will be added to the hook until 200 pounds is reached. The deflection of the surface was be measured and recorded throughout this process in the data sheet given in Appendix N, Table N.2.

To perform a test of a 500 pound distributed load, weights were placed evenly across the surface of the table until the desired weight total weight is achieved. Like with the point load test, the surface deflection was measured throughout the process and recorded in the data sheet given in Appendix N, Table N.3.

For the test to be considered a success, the table should deflect no more than 1/4 of an inch. If at any point during this testing the table tips, the test was to be considered a failure. If at any point the table felt unstable it was to be considered a "soft" failure.

7.3.3 Lateral Loading

There are two situations for lateral loadings, which were considered for testing. The first test models a user leaning on the table and the second test models a user erasing on a table.

To perform a test of a lateral load of 200 pounds, we brought in people to lean on the table. It was more simple and less costly than trying to replicate the loads exerted on the table by other means. The goal of this test was for the table to not slip under these loading conditions. Data for this test to be recorded was whether or not the table slipped given the height of each of the users who will leaned on the four sides of this table as a part of this test. This was all recorded on the data sheet given in Table N.5 of Appendix N.

The eraser test will be performed to measure lateral deflections of the table. The table will then be shaken by using a stand mixer with a weight attached to the paddle at different speeds. The visual deflection was recorded with reference to a ruler placed at the edge of the table. All data taken from this experiment was recorded in a data sheet given in Table N.6 of Appendix N.

For these tests to be deemed a success the table must not slip under loading and the maximum lateral deflection must be under 1/8 of an inch.

7.3.4 Belligerent User Tests

This test has less specific parameters than the other tests for the table. This test included multiple users who attempted to use the table in ways that were not intended. By allowing users to test the table without specific guidelines, we were able to discover potential flaws in our design that we had not even considered. This included having the user climb up onto the table or attempt to assemble and use the table sideways. At the discretion of the supervising engineers, the user may have performed other, unintended activities upon the table to try to generate a full response of the table to unintended use.

7.4 Prototype Test Results

Preliminary testing was completed on the first full table that was built for loading conditions, assessment of manufacturability, and overall usability of the table. The overview of all test results can be found in the DVPR for each assembly throughout Appendix L. Results included in the DVPR and not discussed in depth are the "go/no go" type of results like the weight of the surface which was already predicted while designing this table and the manufacturability of certain component of the table.

7.4.1 Vertical Loading Case Results

Though initial planning for testing the distributed loading conditions only called for a 500 lb loading test, these tests were modified while testing to assess whether the table would be able to support the maximum weight load created by the weights on hand of 590 lb. The table was initially loaded individually with plates then with the remaining sand bags until the maximum weight was reached. The deflection as each bag and plate was unloaded. This data can be found in Table N.3. The table

was loaded to max conditions before having the deflections recorded to ensure that the table would not fail the breaking or tipping test conditions before it reached the specified maximum loading. With the maximum loading of 590 lb, the center of the unsupported edge of the table deflected 9/16 of an inch. At 490 lb, just under the specified loading condition, the table deflected 11/32 in. Though both of these values exceed the maximum allowable deflection conditions of 1/4 in for a horizontal load which was initially specified when setting go/no-go criterion for the table, they are significantly lower than the predicted deflections of 13.67 in calculated in Section I.7. Since the surface significantly out-performed the loading conditions accounted for in our calculations, this test has been deemed successful since, when looking at the table, a deflection of around .5 in is hardly noticeable.

Figure 7.1: Initial distributed loading of plates.

Figure 7.2: Table under full distributed loading conditions.

The next loading test performed was a distributed loading over the unsupported edge of the table. This test intends to model the loading case of a person sitting on the edge of the table, allowing their full weight to rest on the surface. In Figure 7.3, the first bag is placed at the center of the table, sand bags were chosen over plate weights to better model the size and shape of a person sitting on the table. In Figure, 7.4, three sand bags were added to the initial sand bag to bring the weight over 200 lb, which was specified to be tested as a point loading condition. Due to the deflection of the table with four sand bags over the free hanging edge, further sand bags were not added due to the concern for causing permanent damage to the surface.

Figure 7.3: Initial loading of a sand bag over the unsupported edge of the table.

Figure 7.4: Full loading of sand bags over the unsupported edge of the table.

This deflection seen in Figure 7.5 is 1 3/8 inches under a loading of 207.8 pounds. Again, this deflection is much greater than the initial deflection which was specified as allowable in the initial design phase of this project. However, it is significantly lower than the maximum loading which was predicted from our calculations in Section I.7, which helps to validate that our surface is stronger than expected to be.

Figure 7.5: Visible deflection produced from loading the unsupported edge of the table

Once this round of testing was completed, the tipping tests began. These tests intended to model the effect of a person sitting on the edge of the table, seen in Figure 7.6 and Figure 7.7, which initial calculations implied would cause the table to tip or cause the magnetic latch to detach from the steel channel on the back of the surface. For these tests, sand bags were loaded one at a time until six bags were stacked on each corner, commentary on this testing as each bag was loaded can be found in Table N.4.

Figure 7.6: Loading of sand bags over the front left corner of the surface.

Figure 7.7: Loading of sand bags over the front right corner of the surface

During the loading case seen in Figure 7.6, there were no notable changes in the state of the table. Overall, the table was stable and easily held the loads that were placed upon it. The latches stayed engaged with the channel and there was no tipping of the table towards the left corner.

The same cannot be said for the loading case seen in Figure 7.7. With this loading case, the back left leg of the table departed from the ground when the first bag was placed, seen in Figure 7.8. The back left leg on this prototype is known to be shorter than the other legs of the table, requiring the maximum extension of the leveling cap to bring the table to be level overall. The tipping which occurred is likely due to the the fact that the prototype itself is not as level as was desired over there being any clear problems with the design and components used.

Figure 7.8: Back left leg of the table above the ground with loading on the front right corner of the table.

After completing tests to see how much loading the table could withstand, tests were performed to determine how much force was required to remove the surface from the frame. Empirically gathered data determined that an impulse along the back edge of the table is typically one of the best ways to deactivate the magnet latches. The next set of testing worked to determine exactly how much force was required to remove the surface. The data for this can be found in Table N.7.

7.4.2 Horizontal Loading Case Results

The horizontal loading tests for this table are comprised of two main sections: testing human loading with a "lean test" and testing the effects of eccentric vibrational loads on the table through the "eraser test". The "lean test" does not differ much from its name as it require a user to lean on the table at different and observe and record the response of the table to that loading. The "eraser test" intends to be a repeatable model of someone using an eraser while at the table. To ensure that the test is repeatable, a stand mixer will be implemented to have a set eccentric loading on the table but this will not be completed on the prototype model.

The "lean tests" required users to lean on the table and observe the response. The results from this test have been recorded in Table N.5. When a user leaned onto the sides of the table, there was no clear response of the table as this loading condition allowed for there to be the highest amount of friction between the table and the user. In this configuration, seen in Figure 7.9, allowed the casters to be disengaged while the back levelers were engaged so that the table did not move. In this loading condition, the table very clearly passed the requirements set in the pass/fail criteria for this table.

Figure 7.9: A user leaning on the side of the table to test the response of the table to that loading case.

The next testing cases did not have the same level of success as the side loading condition. These loading cases can be seen in Figures 7.10 and 7.11. When users leaned on the front of the tables, the front wheels lifted off of the ground and the table began to tip onto its back legs. When users leaned on the back side of the table, the table began to roll away. The table was not supposed to move significantly under any loading so these loading conditions are considered to be a failure.

Due to the failure of these tests, a redesign of the table, or a restriction on the recommended usage of the table must be considered for future iterations. A redesign could be a selection of different casters on the front of the table to reduce the likelihood of slipping or replacing all wheels with locking casters so that slipping is expected with the design and does not come as a shock to users.

Figure 7.10: A user leaning on the front of the table to test the response of the table to that loading case.

Figure 7.11: A user leaning on the back of the table to test the response of the table to that loading case.

7.5 Final Model Test Results

Three tests were saved for the testing once the final prototype was completed. These tests were the set up tests, the pop off tests, the eraser test and the belligerent user tests. Because the fit between the surface and the sleeves was a determining factor for these tests, they could not be completed until the final prototype was completed.

7.5.1 Eraser Test Results

To model a person erasing violently, an empty stand mixer was set up on the table and turned through different settings. When turning the mixer to its highest setting failed to cause any motion to the table, a 2.5 lb weight was attached to the paddle to see if that would cause the table to shake more. This set up can be seen in Figures 7.12 and 7.13.

Figure 7.12: Stand mixer set up on the table.

Figure 7.13: Attachment of 2.5 lb weight to the paddle.

Instead of using a cone attached to the wall, the motion of the table was visually observed and recorded with reference to a ruler. The results for this testing can be found in Table N.6.

Although it was planned to have the mixer run through its full range of settings. Testing was cut short when the weight came loose from the paddle while on mixer setting 4. At this setting, the table was shaking violently at this setting above the 1/8 in max deflection which was designated earlier, suggesting that higher settings would have caused greater deflections.

The lack of success with this test suggests that a redesign of the support elements of the table may be considered meaning that new casters could be chosen for future iterations of the table or a different surface attachment method could also be useful.

7.5.2 Pop Off Tests Results

To determine whether or not the channel would pop off of the back channel with a loser fit between the surface and pins like what existed on the prototype table, the pop off tests were performed on the final table. Both front corners were tested to see how much force could be applied before the table popped off of its back latches as seen in Figures 7.14 and 7.15. The deflections for each loading of the table can be found in Table N.2.

Figure 7.14: Set up and max loading on the front left corner without causing pop off.

Figure 7.15: Set Up of the loading on the front right corner.

With just a 15 lb load applied to the front left corner, the back left latch detached form the back channel. Given that the table was expected to be able to support a loading of 200 lb, this is one of the most apparent failures in testing for this table.

The front right corner was able to support a load of 40 lb before pop off occurred. In Figures 7.16 and 7.17, we see the increasing loads which could be applied to the right corner of the table.

Figure 7.16: All avalible 5 lb weights applied to the table.

Figure 7.17: 5 lb weights replaced with a 35 lb to achieve greater loadings.

The final load applied to the table before pop off was 40 lb, seen in Figure 7.18. We can see the maximum loading to the table before both back latches detached from the back channel. However, like with the front left corner, not being able to support a load of 200 lb causes the front right corner to also be a failure.

Figure 7.18: Maximum loading on the right corner before pop off occurred.

Due to the location of the final pins on the table, the latches were not placed where they were originally intended to be. Some of the failures in testing could be due to the lack of full engagement with the channel with the latches.

Further testing should be performed on future surfaces to determine when pop-off occurs with a the pins in the correct location, so that the latches can be placed on the back end cap, allowing for full contact of the magnet and the support channel.

7.5.3 Set Up Tests Results

For the set up test, five volunteers of different heights were brought in and asked to set up the table three times to determine how long it takes a user who is unfamiliar with the table set up. The results of this test have been recorded in Table N.1.

Of the major, system level tests, this was the largest success. Since the average time to set up the table was 9.32 seconds with a max time to set up of 26.18 seconds which is still under the maximum set up time of 60 seconds. In addition to this, each user was able to remove the surface in under a

second, thus this time was not recorded due to difficulty in timing such a short duration with any sort of precision.

Since heights of the volunteers were also recorded as a part of this testing, there appears to be no real correlation between a user's height and their ability to place the surface quickly.

7.5.4 Belligerent User Tests

To complete testing, the table was left in the mechatronics lab for a week. To see how the table would withstand a classroom environment where full prototyping occurs, this lab is the best test location to see how well the table withstands misuse. As seen in Figure 7.19, the table is able to withstand being used as a platform to saw on.

Figure 7.19: The table in use by a senior project team.

After lasting for a week with minimal noticeable sustained damage, other than the PVC sleeve on the front right side having an even looser fit with the hole that it protects. A redesign of the hole protection method may be considered to have something that is more durable for future use.

8 Recommendations and Conclusions

Before more of these tables are made, there are some factors that should be taken into consideration to improve the manufacturability and design aesthetic of the table.

8.1 Manufacturing Recommendations

Before more of these table are to be made, there need to be more considerations made for ease of manufacturability. There are two approaches that could be taken to make these tables more east to manufacture, particularly when it comes to welding the frame together. The first would be to redesign the table to alleviate the difficulty in welding table together at the 60° angles. To do this, the orientation of the legs could be changed to allow for the sides of the tables to be welded together before they are attached to the top surface of the table as demonstrated in Figures 8.1, 8.2, and 8.3. The only part of the design that changes here is that the front bar is a 24" piece with 30° angles cut into its front sides and the side bars have been shortened to about 21".

Figure 8.1: Reoriented legs to allow for better ease of manufacturing.

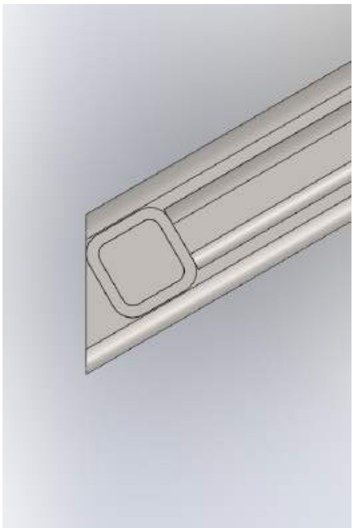


Figure 8.2: Lower supports would be perpendicular to the back legs.

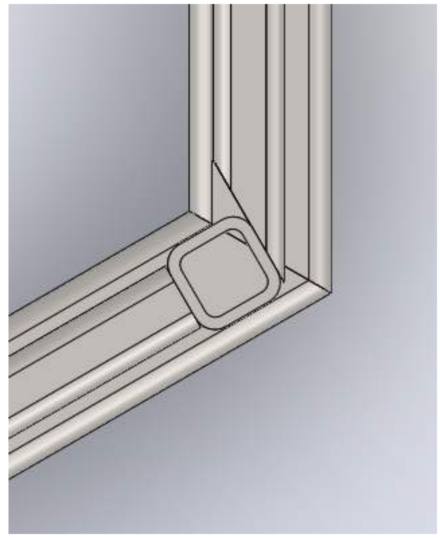


Figure 8.3: Side supports are perpendicular to the front legs as well while front support is now the only piece cut at a severe angle.

Another change to improve manufacturability would be to develop jigging which could be use to hold the supports at a desired height instead of causing the welder to improvise a way to achieve the desired heights. Specific jigs could also be used to hold the uprights in position to supplement what the magnetic supports already do and to speed up the process. Also, further measurement devices could be designed and used to ensure that all tables will have the same measurements.

Since the end caps on the back of the table only serve the purpose to have a space to mount the magnetic latches to, a future iteration of this design could source a cap, like the one used on the bottom of the back legs, to cover the back holes. This would decrease the time that it takes to cut and weld the small rectangle to the back piece of the frame.

The paint which was chosen to coat the frame has begun to chip off after mild usage of the table and should be resourced prior to finishing more frames.

8.2 Surface Design Changes

In an attempt to reduce the costs for the surface of the table, PVC inserts were selected to fill the holes on the top of the table. These inserts required a very large hole to be drilled into the surface, causing the wood to splinter, ruining the overall finish of one side of the table because so much of the wood needed to be sanded away to remove the splintering. Further splintering occurred upon insertion of the pins. Of the six surfaces which were cut to shape, only two had limited splintering. Figure 8.4 shows the least splintered sleeve.

Figure 8.4: PVC sleeve inserted into the surface.

From an aesthetic stand point, on the formal surface, the PVC insert also cheapens the look of the table so a different reinforcement option should be considered in the future to give the table a more polished look.

In addition to this, the surfaces, being made in accordance with the drawings provided in Appendix D do not line up as expected with back of the table as seen in Figure 8.5. This is primarily due to the location that the holes for the pins were placed. In the future, the pins should be located about .75 inches closer to the front edge of of the surface so that the channel is able to hang off of the back edge of the table and fully engage with the magnetic latches which should be placed on the back edge of the table.

Figure 8.5: PVC sleeve inserted into the surface.

The screws that were used to attach the channel to the surface were not perfectly centered with the middle of the wood and caused extra damage to the surface as seen in Figures 8.6 and 8.7. This could be avoided in the future through using shorter screws to attach the channel to the surface and by taking more care to drill the pilot holes straight down.

Figure 8.6: Screw breaking through birch surface.

Figure 8.7: Screw breaking through white board surface.

8.3 Conclusions on the Final Table

Upon completing the final table, some clear changes that need to be made are immediately apparent. First, the design changes mentioned above must be made so that the table is easier to manufacture and more aesthetically appealing.

Other than the latch location on the back surface of the frame, it matches its intended design. As seen in Figure 8.8, the frame matches the design intent found in Figure 5.5.

Figure 8.8: Final frame.

The latch location needed to be changed to accomodate the final surfaces which were being used with the table, as seen in Figures 8.9 and 8.10. Despite this detail, as a whole, the tables meet the basic design criteria. The actual details of the design could be better reproduced when the table is made in higher production, with more care placed on executing the finer details properly.

Figure 8.9: Final table with formal surface.

Figure 8.10: Final table with MDF surface facing upwards.

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List of Appendices

A House of Quality

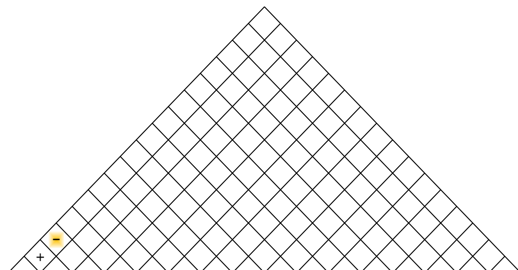
This appendix contains the House of Quality used to evaluate important design details.

QFD: House of Quality
Project: Team Glasses
Revision: 1
Date: 10/18/2016

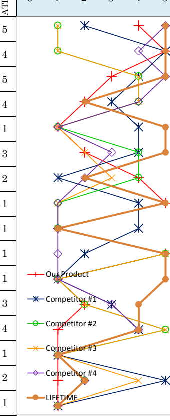
Correlations	
Positive	+
Negative	−
No Correlation	

Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

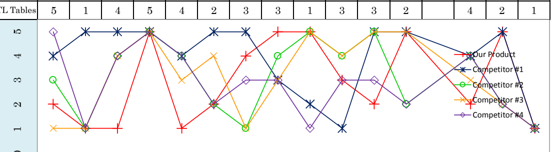


								Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16							
	WHO: Customers							Direction of Improvement	▼	◇	▲	▲	▲	▲	▲	◇	◇	◇	▲	▲	▼	◇	▲	▲	NOW: Current Product Assesment - Customer Requirements						
Row #	Weight Chart	Relative Weight	Design Students	Schuster/Widmann	Shop Techs	Cal Poly	Maximum Relationship	HOW: Engineering Specifications / WHAT: Customer Requirements (explicit & implicit)	Storage Footprint	Table Height	Deflection	Load	Product Life	Set-Up Time	Persons to Operate	Aesthetics	Occupancy	Accessibility	No Pinch Points/Death traps	Time to Build	Cost	Steps to Store	Vertical Tipping Force	Table Area	Bonderson 104 Table	High-Bay Work Table	Fishbowl Table	192-120 Tables	Plastic (Lifetime) Tables	ATL Table	Row #
1		6%	1	9	1	9	9	Small Storage Footprint	●	▽	○		▽			○			○		○			●	4	2	1	1	5	5	1
2		6%	9	9	1	3	9	Easily Configured (quick assembly/dessebly	●	▽	○	▽	▽	●	●	▽			○			●		●	5	5	1	1	5	4	2
3		5%	3	9	1	3	9	Weight Capacity		○	○	●	●				▽	▽	●				●		3	4	4	4	5	5	3
4		6%	9	9	1	3	9	Stable Table	●	●	●	●	●		●	▽	●	○	●		○	▽	●	▽	2	3	4	4	2	4	4
5		6%	9	9	1	1	9	Functional Height (for standing/stooling)	▽	●	●	●			○	▽	●	●	●						1	4	1	1	5	1	5
6		8%	3	9	3	9	9	Longevity			●	●	●						●						2	4	4	2	5	3	6
7		8%	9	9	1	9	9	Aesthetically Pleasing								●					○				4	1	4	3	2	2	8
8		6%	9	9	1	3	9	Portability	▽		●	○	○	▽	○	▽		▽	●		▽	●		○	5	4	1	1	5	1	9
9		12%	1	9	9	9	9	Manufacturability											●	●		○		▽	1	4	1	1	1	1	10
10		6%	9	9	1	3	9	Comfortably seats/stands 4	○	●						▽	●	○	▽					●	5	2	5	5	5	1	11
11		2%	3	1	1	1	9	ADJUSTABLE HEIGHT		●	○	○							○		○				1	1	1	1	5	1	12
12		2%	3	1	1	1	9	Indoor/Outdoor					●			○									2	3	2	2	4	3	13
13		8%	9	9	1	9	9	Safety											●			▽	●		1	4	5	5	4	4	14
14		3%	3	3	1	1	9	Multiple Surfaces													●			▽	1	1	1	1	1	1	15
15		12%	1	9	9	9	9	Ease of Maintenance												●					1	5	2	4	2	2	
16		2%	3	1	1	1	9	OUTLETS											●						1	1	1	1	1	1	16



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
HOW MUCH: Target	10 Tables - ~50 (roughly 5x10)	39"	1/8" max static deflection, eraser test	200 lbs	10 year frame	60 seconds, MAX	One person, one minute	appeals to 75%	4 people	Chairs all around the table	0, MAX	16 hours, MAX	$200	4, MAX	200 lb, MIN	3.5'x4' MIN
Max Relationship	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
Technical Importance Rating	200.97	212.71	297.51	255.85	223.48	64.011	151.6	131.88	171.36	100.95	534.49	214.73	99.201	165.84	175	209.8
Relative Weight	6%	7%	9%	8%	7%	2%	5%	4%	5%	3%	17%	7%	3%	5%	5%	7%
Weight Chart																
Bonderson 104	2	1	1	5	1	2	4	5	5	3	2	5		2	5	1
High Bay Work Table	4	5	5	5	4	5	5	3	2	1	5	5		4	5	1
Fish Bowl Tables	3	1	4	5	4	2	1	4	5	4	5	2		4	2	1
192-120 Tables	1	1	4	5	3	4	1	3	5	4	5	5		3	2	1
Plastic (Lifetime) Tables	5	5	3	5	4	2	5	2	5	3	3	2	5	4	5	1
ATL Tables	5	1	4	5	4	2	3	3	1	3	3	2		4	2	1

Current Product Assesment - Engineering Specifications



Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Template Revision: 0.9 Date: 4/23/2010
Christopher Battles

B Ideation

This appendix documents all ideation sessions which occurred while generating preliminary ideas for this project.

Table B.1: Initial Ideation: Brain Writing and Whiteboard Brain Storming

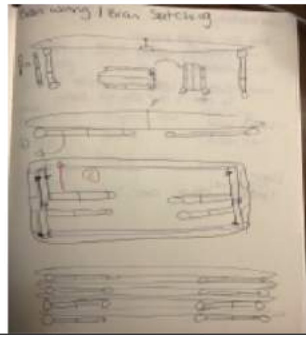
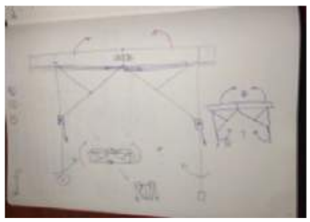
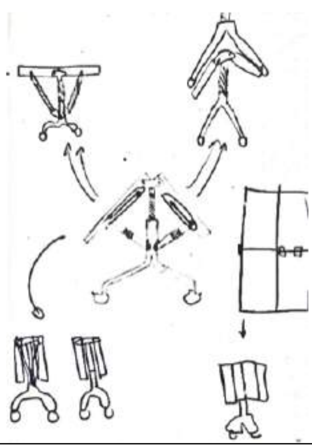
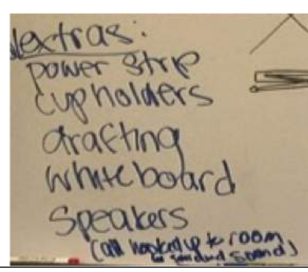
Session	**Idea**	**Sketch**	**Pros**	**Cons**
Brain Writing	Adjustable Legs		Collapsible legs. Adjustable height legs.	Pinch points for days. May take a while to set up. Difficult to manufacture.
	Many Folds/Walker Wheels		Compact storage. Somewhat reconfigurable. Walker wheels provide mobility when wanted, and stability when needed.	Complex design for manufacturing and use. Many potential failure points and pinch points.
	Folds in half to store vertically and partially nested		Surface adjusts angle for drafting. Fairly compact and simple storage.	Complicated design. Pivots and links may hinder table rigidity. Costly and time-consuming to manufacture.
Whiteboard Brain Storming	Extra features		Power strip on the table could allow students to charge their devices.	A power strip on the table top could be a hazard if water is involved.

Table B.1: Initial Ideation: Brain Writing and Whiteboard Brain Storming

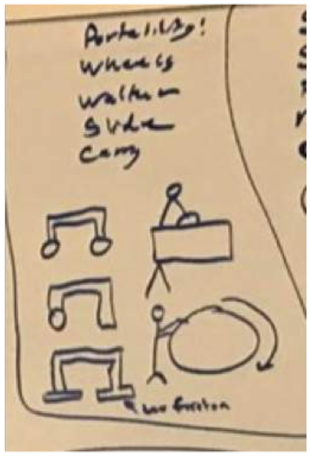
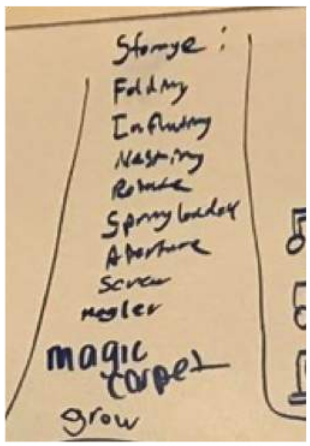
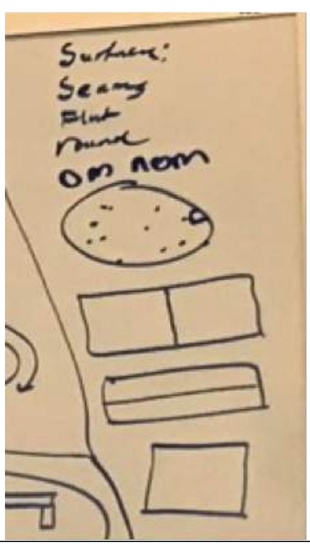
Session	Idea	Sketch	Pros	Cons
Whiteboard Brain Storming	Portability ideas: Wheels, Walker, Sliders, Carry, Roll		Wheels are always portable. Walker provides portability and stability. Sliders provide stability. Carrying means the table is not as limited by obstacles. Rolling can move heavy things efficiently	Wheels might be hard to make stable. Walker might be unbalanced Sliders might damage floor or not provide enough ease of movement. Table might be too heavy to carry. Rolling requires the table to be tilted to move.
	Storage Methods: Folding, Inflating, Nesting, Rotating, Spring Loaded, Aperture, Screw, Magnetic-Levitation, Magic Carpet, Grow		Upper half are all practical and known to work methods of storing tables. Lower half are original and creative	Upper half are relatively boring. Lower half range from impractical to impossible
	Surface Types and storage methods: Seams (for folding), Flat, Round, Cookie		Seams can allow the surface to become more compact. Flat and round solid surfaces can provide stability and reduce pinch points.	Seams can cause failure or pinch points. Solid surface cannot really compact. Cookie is completely impractical.

Table B.2: Extra Features: Outlets, Bag Storage, Drafting, Other.

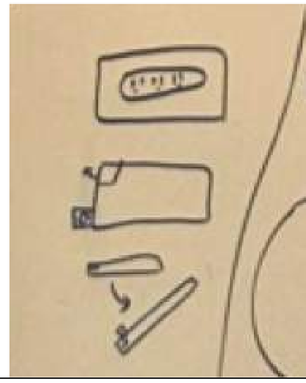
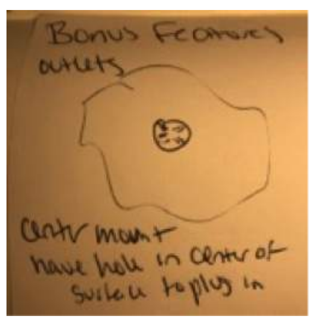
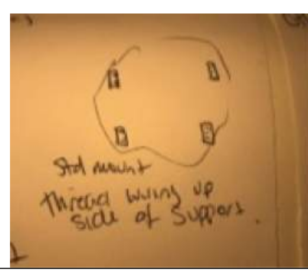
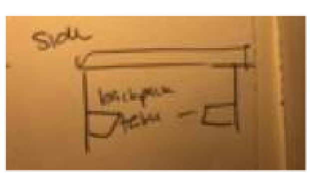
Session	**Feature**	**Idea**	**Sketch**	**Pros**	**Cons**
Cropped Board Doodles	Electricity, Cup Holders, Drafting Lip	Thorough table design		On-board power would be convenient. Cup holders could securely hold drinks nearby to prevent spills. Drafting lip flush when not in use.	Potential electrical hazard/added complexity. Potential pinch points.
6 Sheets in the Library	Miscellaneous	The Kitchen Sink		Includes a footrest and/or personal item storage rack underneath. Edge can be clamped to. Hooks for backpacks. Integrated power outlets.	Cost. Difficulty of implementation
	Outlets	Center mount support		Convenient outlet location. Ensures that the need to charge devices would not detract from collaboration.	Potential fire hazard if water is spilled onto the table. Need to wire these outlets through the legs.
		Side mount support		Convenient outlet location. Ensures that the need to charge devices would not detract from collaboration.	Potential fire hazard if water is spilled onto the table. Need to wire these outlets through the legs.
	Backpack rest	Support off of side leg		People do not have to lean down to the ground to get backpack.	Potential for injury if someone runs into it.

Table B.2: Extra Features: Outlets, Bag Storage, Drafting, Other.

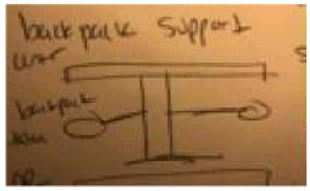
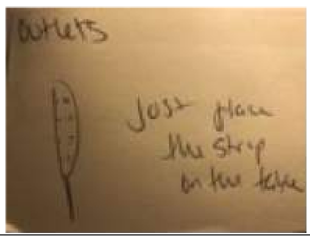
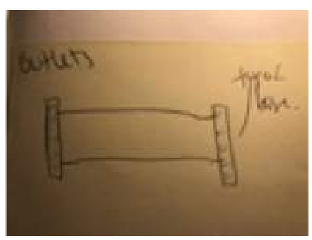
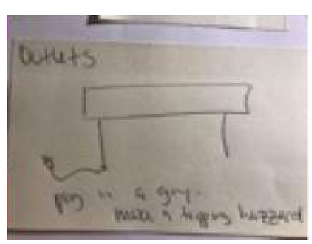
Session	**Feature**	**Idea**	**Sketch**	**Pros**	**Cons**
Sticky Notes	Backpack rest	Support off of middle support		People do not have to lean down to the ground to get backpack.	Potential for injury if someone runs into it.
	Outlets	Outlets located at the top of a center support base.		Convenient outlet location. Ensures that the need to charge devices would not detract from collaboration.	Potential fire hazard if water is spilled onto the table. Need to wire these outlets through the legs.
		Using a power-strip		Easy to purchase and implement.	Potential fire hazard if water is spilled onto the power strip.
		Outlets located at the top of a side mounted or expanding base.		Convenient outlet location. Ensures that the need to charge devices would not detract from collaboration.	Potential fire hazard if water is spilled onto the table. Need to wire these outlets through the legs.
		Outlets which line the side of the surface.		Convenient outlet location. Ensures that the need to charge devices would not detract from collaboration.	Need to wire these outlets through the legs.
		Power supply to outlet threaded through a table leg.		Necessary to have outlets on the table without a battery.	Potential tripping hazard. Limits freedom of motion for the table.

Table B.3: Compacting Methods

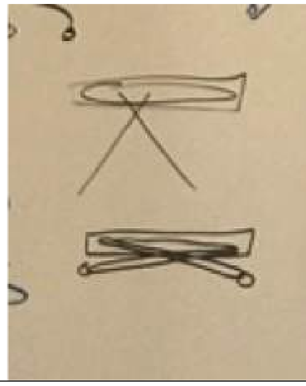
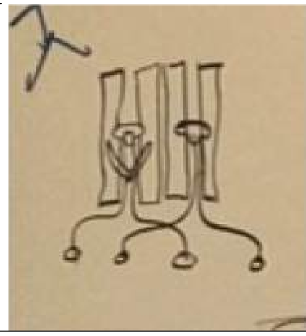
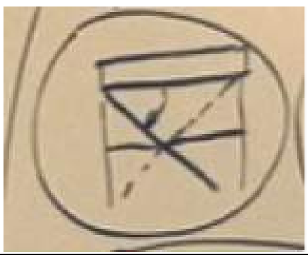
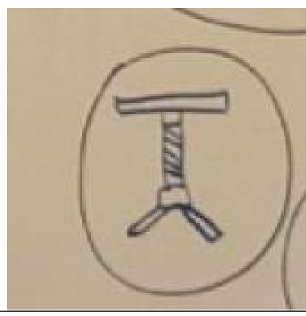
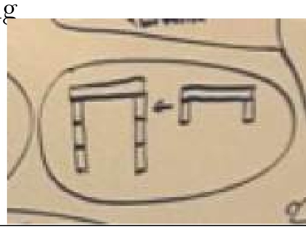
Session	Feature	Idea	Sketch	Pros	Cons
Whiteboard Brain Storming	Folding	Scissor Table		Simple design, easy to manufacture/know it works. Potential for multiple heights	Pinch points for days
		Centerfold Tables		Potential to angle for multiple drafting surfaces.	More pinch points.
		Card table style legs		Easy to set up	Not particularly stable
		Large threads may be difficult to manufacture		Variable height, likely intuitive design	con
		Telescoping legged table		Adjustable heights at different telescoped lengths	Might not be as stable if legs fail

Table B.3: Compacting Methods

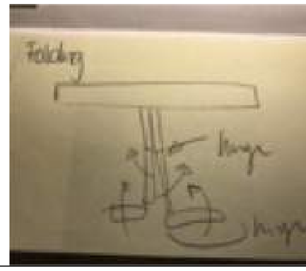
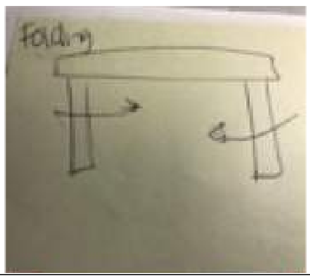
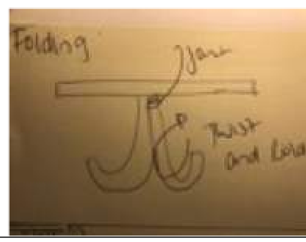
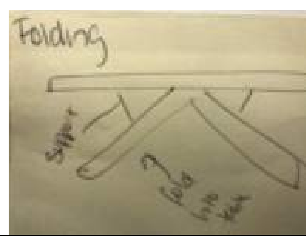
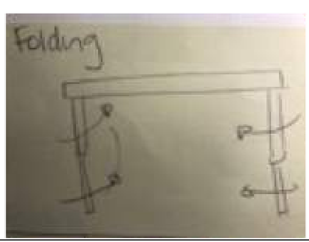
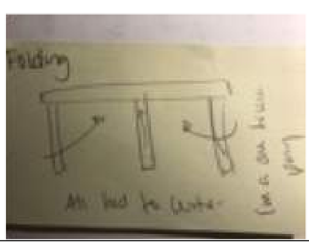
Session	Feature	Idea	Sketch	Pros	Cons
Sticky Notes	Expanding	Double hinge with foot supports		Interesting system. Folds down small.	Difficult to manufacture. Potentially not intuitive to set up. Pinch points.
		Outer legs fold in towards the center		Folds down compactly.	Difficult to manufacture. Potentially not intuitive to set up. Pinch points.
		Twist and fold down.		Interesting mechanism.	Difficult to manufacture. Potentially not intuitive to set up. Pinch points.
		Adjust pin angle to fold down legs		Pins could also allow for a change in height of the table.	Difficult to manufacture. Potentially not intuitive to set up. Pinch points.
		Double fold on the sides		Interesting mechanism.	Difficult to manufacture. Potentially not intuitive to set up. Pinch points.
		Sides fold towards the center		Simple but strong design.	Difficult to manufacture. Potentially not intuitive to set up. Pinch points.

Table B.3: Compacting Methods

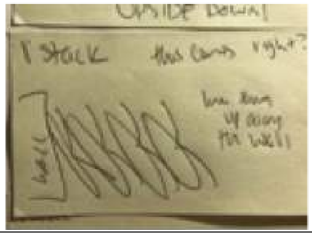
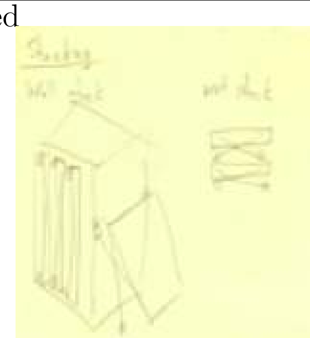
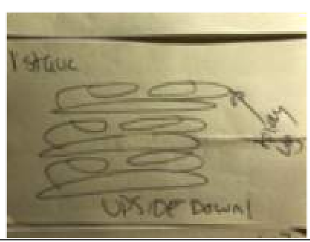
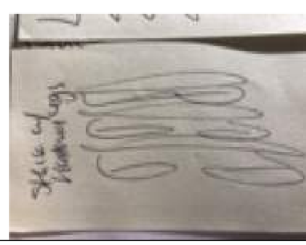
Session	Feature	Idea	Sketch	Pros	Cons
Sticky Notes	Stacking	Tables leaning against the wall		Storage footprint is that of just one table.	Table must be lifted to be stacked.
		Designated Leaning		Tables are stored out of the way and the useful space of the room is maximized in the wall stack.	Probably need to design a physical-input based system to help user raise tables into storage.
		Direct Stacking		Removed surface allows table frame is stored very compactly on one another.	Frame, although lighter without the surface, still has to be lifted for storage.
		Nested Stack		Useful square footage of room is maximized.	Physically lifting table is not really a viable option due to hazards.
		Tables fold and stack on top of each other		Useful square footage of room is maximized.	Physically lifting table is not really a viable option due to hazards
		Tables fold and stack on top of each other		Storage footprint is that of just one table.	Table must be lifted to be stacked.

Table B.3: Compacting Methods

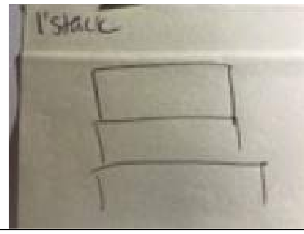
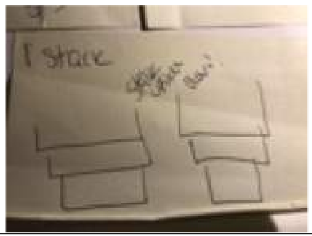
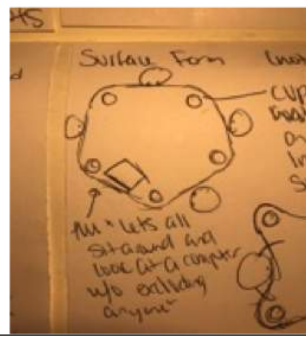
Session	Feature	Idea	Sketch	Pros	Cons
Sticky Notes	Stacking	Tables fold and stack on top of each other		Storage footprint is that of just one table.	Table must be lifted to be stacked.
		Tables stack on top of each other		Storage footprint is that of just one table.	Table must be lifted to be stacked. Cannot stack very many tables.
		Tables stack on top of each other upside down		Storage footprint is that of just one table.	Table must be lifted to be stacked.Cannot stack very many tables.

Table B.4: Non-Standard Surface Shape

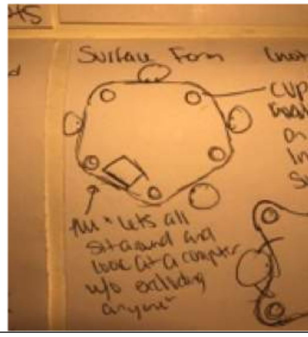
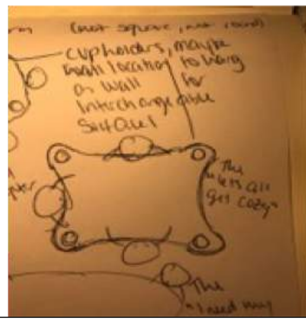
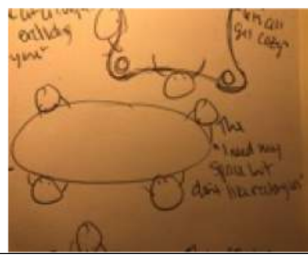
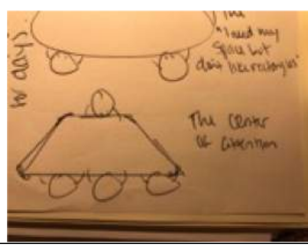
Session	**Idea**	**Sketch**	**Pros**	**Cons**
6 Sheets in the Library	Pentagon		Allows for groups larger than 4. Gives ample space for computers.	Potential waste in making this shape. Likely hard to manufacture.
	Hyperbola		Allows people to lean into the table without invading the space of others.	Potential waste in making this shape. Likely hard to manufacture.
	Oval		Allows for ample room to work.	Potential waste in making this shape. Likely hard to manufacture.
	Trapezoid		Two trapezoids could be combined to make a hexagon to allow more people to work together.	Potential waste in making this shape. Likely hard to manufacture.

Table B.5: Support Location

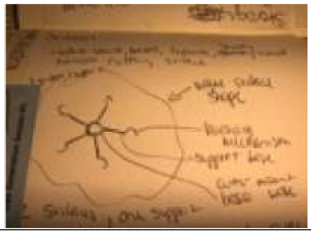
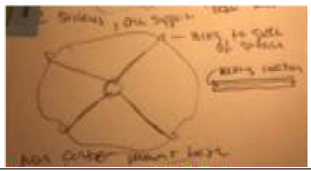
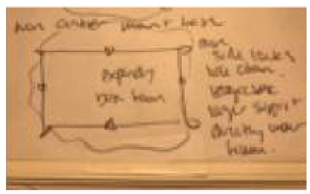
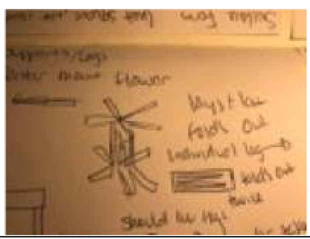
Session	Idea	Sketch	Pros	Cons
6 Sheets in the Library	Center mount clamps to mid surface		Secure connection to the table.	Likely difficult to manufacture. Potentially not intuitive.
	Center mount clamps to outside		Secure connection to the table.	Likely difficult to manufacture. Potentially not intuitive.
	Expandable base attaches to the sides of the surface.		Secure connection to the table.	Likely difficult to manufacture. Potentially not intuitive.
	Center-mount flower table		Many points for support with the ground and the table.	Likely hard to manufacture. Will have many pinch points. Potentially not intuitive to set up.

Table B.6: Storage Methods

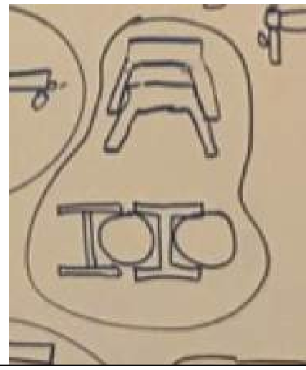
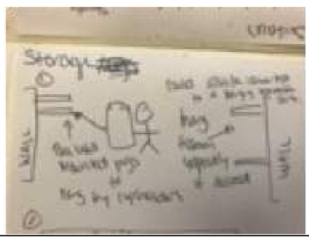
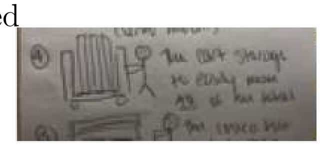
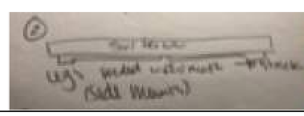
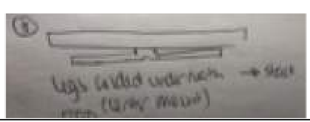
Session	Feature	Idea	Sketch	Pros	Cons
		Circular nesting		No moving parts, likely easier to manufacture and more stable	Potentially not compact storage, very few additional features
		Hanging Surface Storage		Designated storage space.	Obtaining approval to modify the room. Storage area would be difficult to re-purpose.
		Designated Cart		Easy to transport multiple tables at a time.	A cart must be designed and constructed. Tables must be lifted onto cart.
		Designated Flatbed		Easy to transport multiple tables at a time.	A cart must be designed and constructed. Tables must be lifted onto cart.
		Folding Side Mount		Folds flat. Stacks easily.	Potential pinching when folding legs down.
		Folding Center mount		Folds flat. Stacks easily.	Potential pinching when folding legs down
		Nesting circular tables of different sizes		Many sizes of tables. Versatility.	Must make tables of many sizes. Everyone has a different height/size of table.

Table B.6: Storage Methods

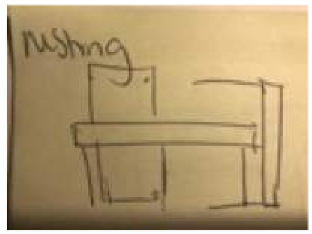
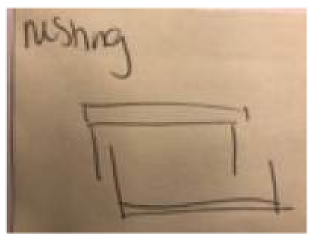
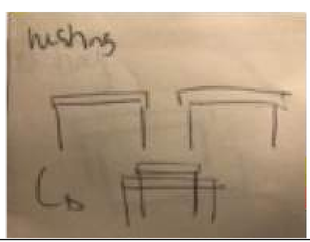
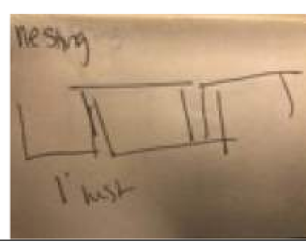
Session	Feature	Idea	Sketch	Pros	Cons
		Nesting rectangular tables of different sizes		Many sizes of tables. Versatility.	Must make tables of many sizes. Everyone has a different height/size of table.
		Nesting tables of the same size in interesting configurations		Tables are all the same size.	Not an efficient nesting system. Table must be lifted to be nested.
		Nesting tables of the same size in less interesting configurations		Tables are all the same size.	Not an efficient nesting system. Table must be lifted to be nested.
		Nesting tables by stacking them		Tables are all the same size.	Not an efficient nesting system. Tables must be lifted up in order to properly nest.
		Nesting multiple tables together		Tables are all the same size.	Not an efficient nesting system. Table must be lifted to be nested.

Table B.6: Storage Methods

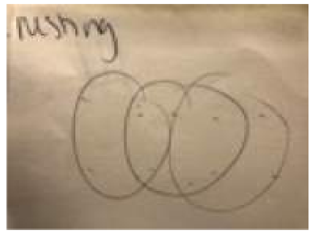
Session	Feature	Idea	Sketch	Pros	Cons
		Nesting circular tables of the same size on their side		Tables are all the same size.	Not an efficient nesting system. Table must be lifted to be nested.

Table B.7: Adjustable Features: Height, Size, Angle, Surface.

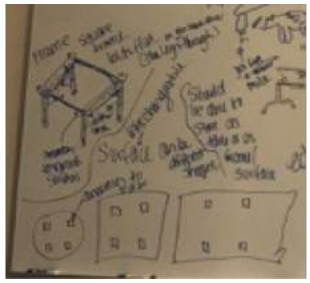
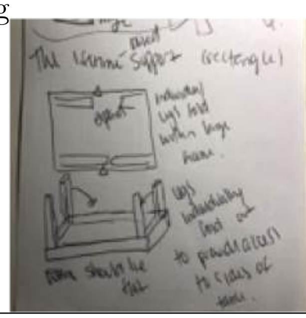
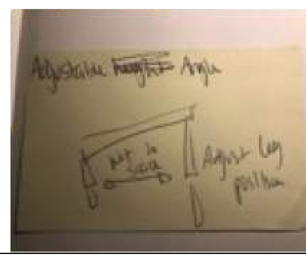
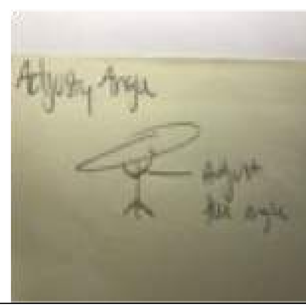
Session	Feature	Idea	Sketch	Pros	Cons
		Support system		Base expands. Base can be used with multiple surface shapes. Potential open holes for hanging storage.	Likely difficult to manufacture.
		Expanding Side Mounts		Standard basic table shape. Should be supportive and rigid. Expands to a table size.	Likely hard to manufacture. Will have many pinch points. Potentially not intuitive to set up.
		Changing leg height		Angles for drafting.	Difficult to manufacture. Potentially not intuitive to set up.
		Changing angle		Angles for drafting.	Difficult to manufacture. Potentially not intuitive to set up.
		Hinged at edge		Simple to incorporate a hinge and support system to retain surface.	Requires a mechanism support to prevent surface from falling that the user has to move.

Table B.7: Adjustable Features: Height, Size, Angle, Surface.

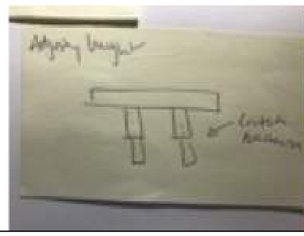
Session	Feature	Idea	Sketch	Pros	Cons
		Center lift linkage		Lifts a bifurcated table to angle both halves at same time.	Could be a complicated mechanism that poorly effects table rigidity.
		Crutch mechanism		Known, functional design. Existing technology could be utilized.	Difficult to manufacture. Potentially not intuitive to set up.
		Pneumatic Chair Cylinder		Powerful and quick cylinder allows for quick adjustments. Easy and familiar user interface.	May be hard to allow piston to go down. Would have to implement a pressure release system
		Telescoping legs with Spring-loaded Locking Pins		Very cheap to manufacture. Very simple to implement.	Large clearance in holes may reduce rigidity of table while in use. Inconvenient for user to adjust table on its side.

Table B.8: Unfeasible Ideas.

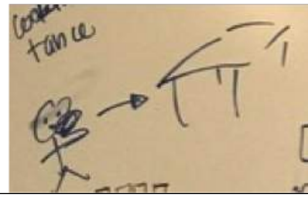
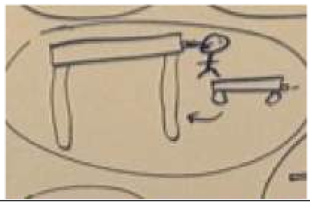
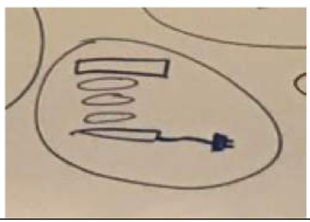
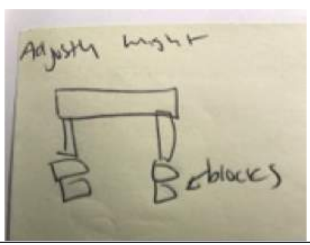
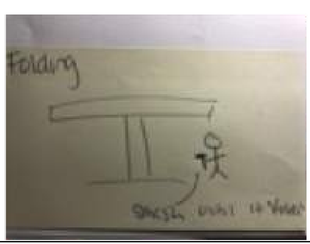
Session	Idea	Sketch	Pros	Cons
Whiteboard Brain Storming	Inflatable Table		Very small storage space.	Lengthy set up/take down time. Has to be blown up each time. Potential instability or easy to pop.
	Inflatable Legged Table		Small storage.	Lengthy set up/take down. Has to be blown up each time.
	Mag-Lev table		Epic Idea.	May affect computers. Completely impractical.
Sticky Notes	Adjustable Height: Put the table on blocks		Simple design.	Impractical
	Adjustable Height: Cables attached to the ceiling		Interesting design.	Difficult to manufacture. Potentially not intuitive to set up.
	Folding: smash the base to fold the supports.		None	Impractical

Table B.9: Full Fledged Ideas and 3D Models.

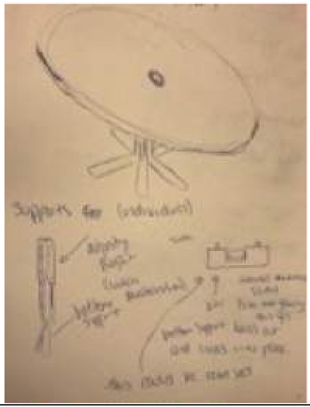
Session	Idea	Sketch	Pros	Cons
	The Squid		Aesthetically interesting. Outlets incorporated into base design. Adjustable height.	Potentially difficult to manufacture.
	The Drafter		Angles for drafting.	Difficult to manufacture.
	The Squid		Interesting design. Potential use with multiple surfaces. Accessible from all sides.	Difficult to manufacture. Potentially not intuitive to set up.
	The Square		Designed for Interchangeable surface. Base expands. Legs could adjust. Aesthetic AF.	Difficult to manufacture. Potentially not intuitive to set up.

Table B.9: Full Fledged Ideas and 3D Models.

Session	Idea	Sketch	Pros	Cons
	Collapsible legged table		Collapses easily. Access to all sides of the table.	Not particularly stable. Complex design increases chances of failure
	Hinged Nester		Stores like a shopping cart	Potentially dangerous if the surface falls onto the user or other tables
	Small trapezoids		Simple. Easy to make. Unusual shape.	Requires lifting to be stored. Not very compact
	Pegged Trapezoids		Modification of the nesting trapezoid. Allows for interchangeable surfaces	Might not be most secure method to hold surface.

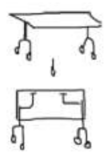
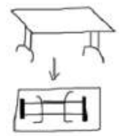
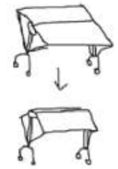
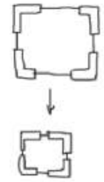
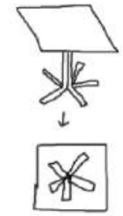
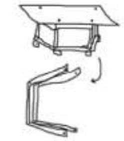
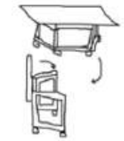
Table B.9: Full Fledged Ideas and 3D Models.

Session	Idea	Sketch	Pros	Cons
	Full Scale Trape-zoidal Table		Allows for a better "feel" of the model. Allows for a better idea of the size of the table.	Not yet a practical model

C Full Pugh Matrix

This appendix contains the full sized pugh matrix used to assess the top ideas against the existing tables.

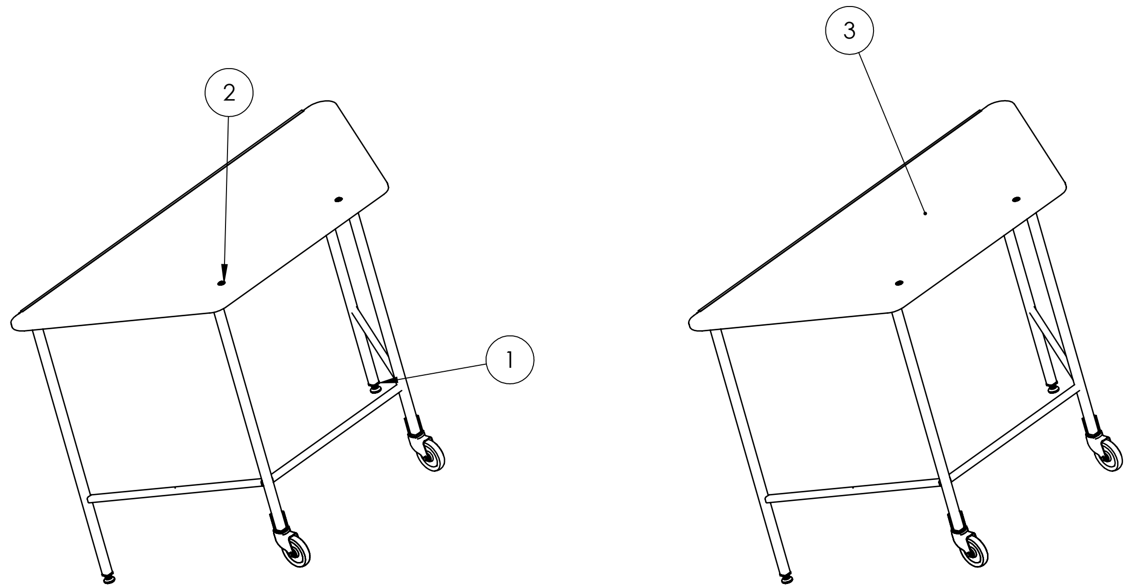
Table C.1: Full system Pugh Matrix.

Criteria	 **Baseline (Bonderson 104)**	 **High Bay**	 **Folding (Lifetime)**	 **Keter**	 **Center Seam**	 **Telescoping Frame**	 **Squid**	 **Rigid Nesting**	 **Frame +Surface Nesting**	 **Nesting with Hinged Surface**
Static Stability	0	1	0	1	1	0	0	1	1	1
Dynamic Stability	0	1	1	1	1	0	0	1	0	0
Compactness when stored	0	-1	1	1	0	1	1	-1	1	0
Safety	0	1	0	-1	0	-1	0	1	-1	-1
Complexity of reconfiguration	0	1	0	0	0	0	-1	1	1	1
Physical Ease of Use	0	-1	-1	1	0	-1	-1	-1	-1	0
Height	0	1	1	1	1	1	1	1	1	1
Aesthetics	0	1	-1	-1	1	0	1	0	1	1
Leg Interference	0	-1	0	-1	0	1	1	-1	1	1
Complexity of Design/Build	0	-1	0	-1	-1	1	1	1	1	-1
Cost	0	0	1	1	-1	0	-1	1	1	0
Sum	**0**	**2**	**2**	**0**	**2**	**2**	**2**	**4**	**6**	**3**

D Technical Drawings

Drawing List

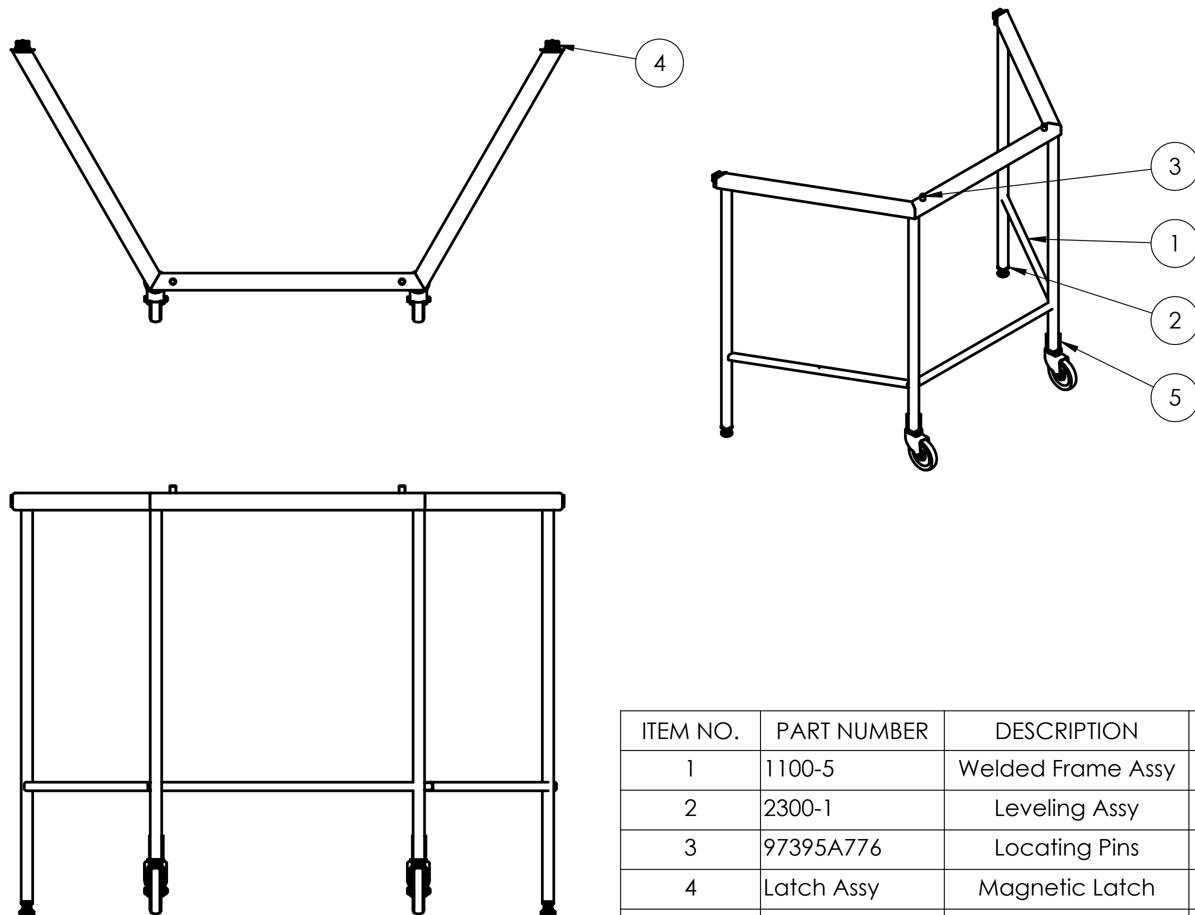
- 100 - Top Level Assembly Both Surfaces
- 200 - Frame Assembly
  - 210 – Frame Weld Assembly
    - 211 – Frame Tubing Cut Drawing
  - 220 - Caster Assembly
    - 221 - Caster Specification Sheet
  - 230 - Leveling Assembly
  - 240 - Pin Drawing
  - 250 - Latch Assembly
    - 251 - Base Drawing
    - 252 - Latch Drawing
    - 253 - Latch Specification Sheet
- 300 - Work Surface Assembly
    - 301 - Exploded Work Surface Assembly
  - 310 - MDF Surface Drawing
    - 311 - MDF Specification Sheet
  - 320 - Table Components Drawing
  - 330 - Dry Erase Paint Specification Sheet
- 400 - Formal Surface Assembly
  - 410 - Plywood Drawing
    - 411 - Plywood Specification Sheet
  - 420 - Varnish Specification
- 500 - Cart Specification Sheet



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1000-5	Full Frame Assy	1
2	4000-1	Formal Surface Assy	1
3	3000-1	Work Surface Assy	1

Cal Poly Mechanical Engineering	Lab Section: 02	Assembly: 1000-1	Title: Final Table Assemblies		Drwn. By: CP Table Top
ME 430 - Spring 2017	Dwg. #: 100	Sub Assy: n/a	Date: 6/2/2017	Scale: 1:16	Chkd. By: ME STAFF

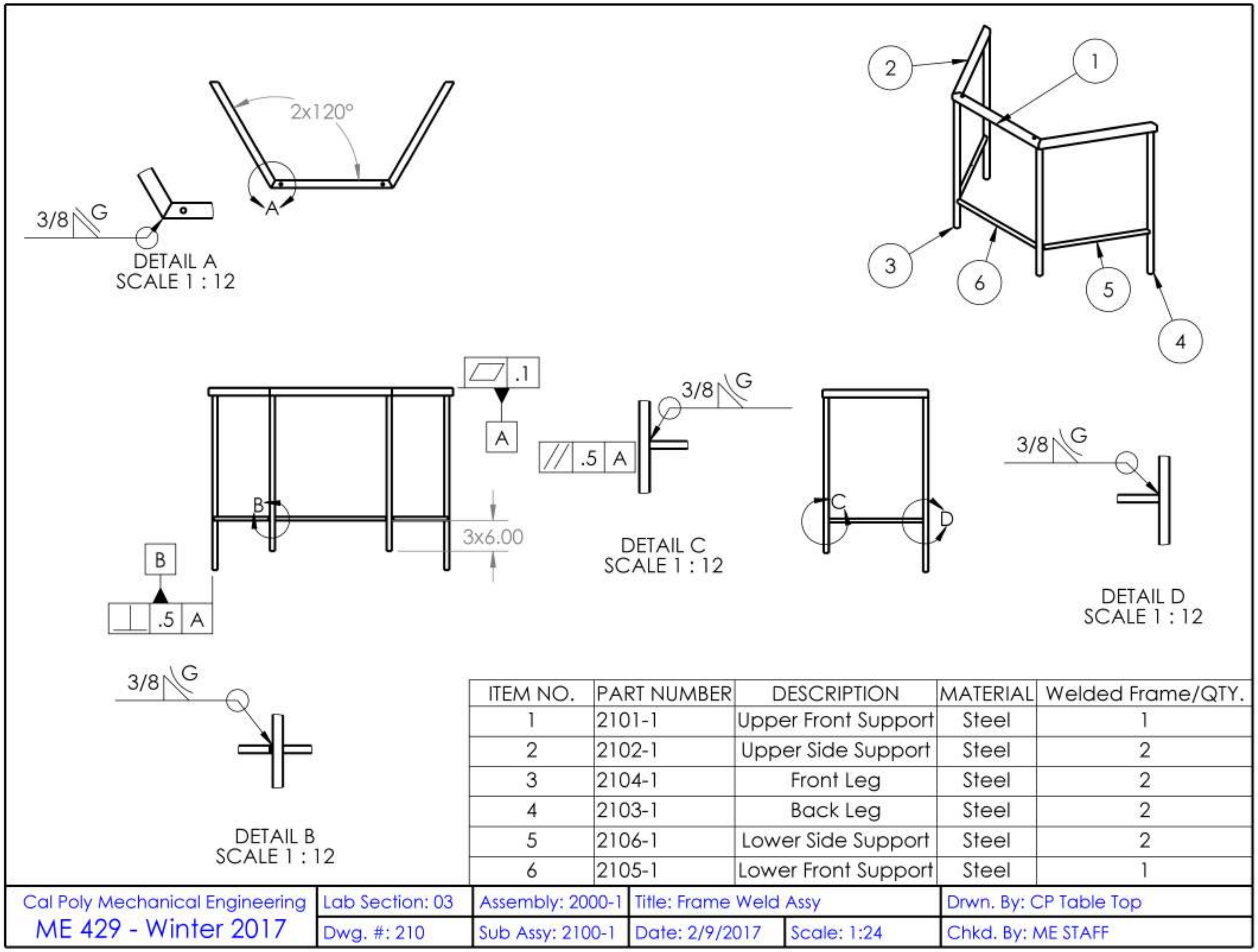
Figure D.1: Drawing 100 - Top Level Assembly, Both Surfaces



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1100-5	Welded Frame Assy	1
2	2300-1	Leveling Assy	2
3	97395A776	Locating Pins	2
4	Latch Assy	Magnetic Latch	2
5	2399T3	Angle Mount Caster	2

Cal Poly Mechanical Engineering	Lab Section: 02	Assembly: 2000-1	Title: Frame Assembly		Drwn. By: CP Table Top
ME 430 - Spring 2017	Dwg. #: 200	Sub Assy: n/a	Date: 6/2/2017	Scale: 1:16	Chkd. By: ME STAFF

Figure D.2: Drawing 200 - Frame Assembly



ITEM NO.	PART NUMBER	DESCRIPTION	MATERIAL	Welded Frame/QTY.
1	2101-1	Upper Front Support	Steel	1
2	2102-1	Upper Side Support	Steel	2
3	2104-1	Front Leg	Steel	2
4	2103-1	Back Leg	Steel	2
5	2106-1	Lower Side Support	Steel	2
6	2105-1	Lower Front Support	Steel	1

Cal Poly Mechanical Engineering	Lab Section: 03	Assembly: 2000-1	Title: Frame Weld Assy		Drwn. By: CP Table Top
ME 429 - Winter 2017	Dwg. #: 210	Sub Assy: 2100-1	Date: 2/9/2017	Scale: 1:24	Chkd. By: ME STAFF

Figure D.3: Drawing 210 - Frame Weld Assembly

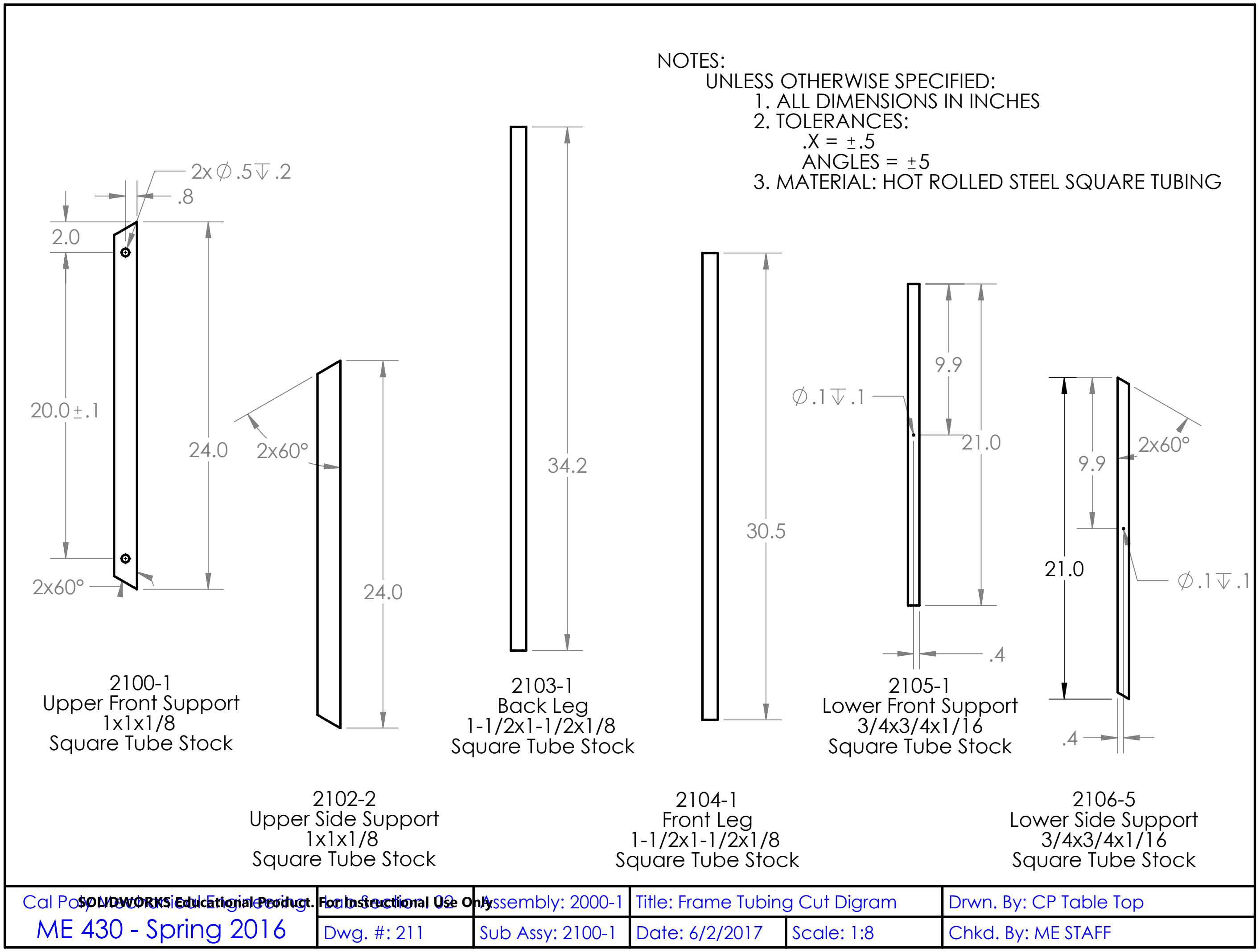


Figure D.4: Drawing 211 - Frame Tubing Cut Drawing

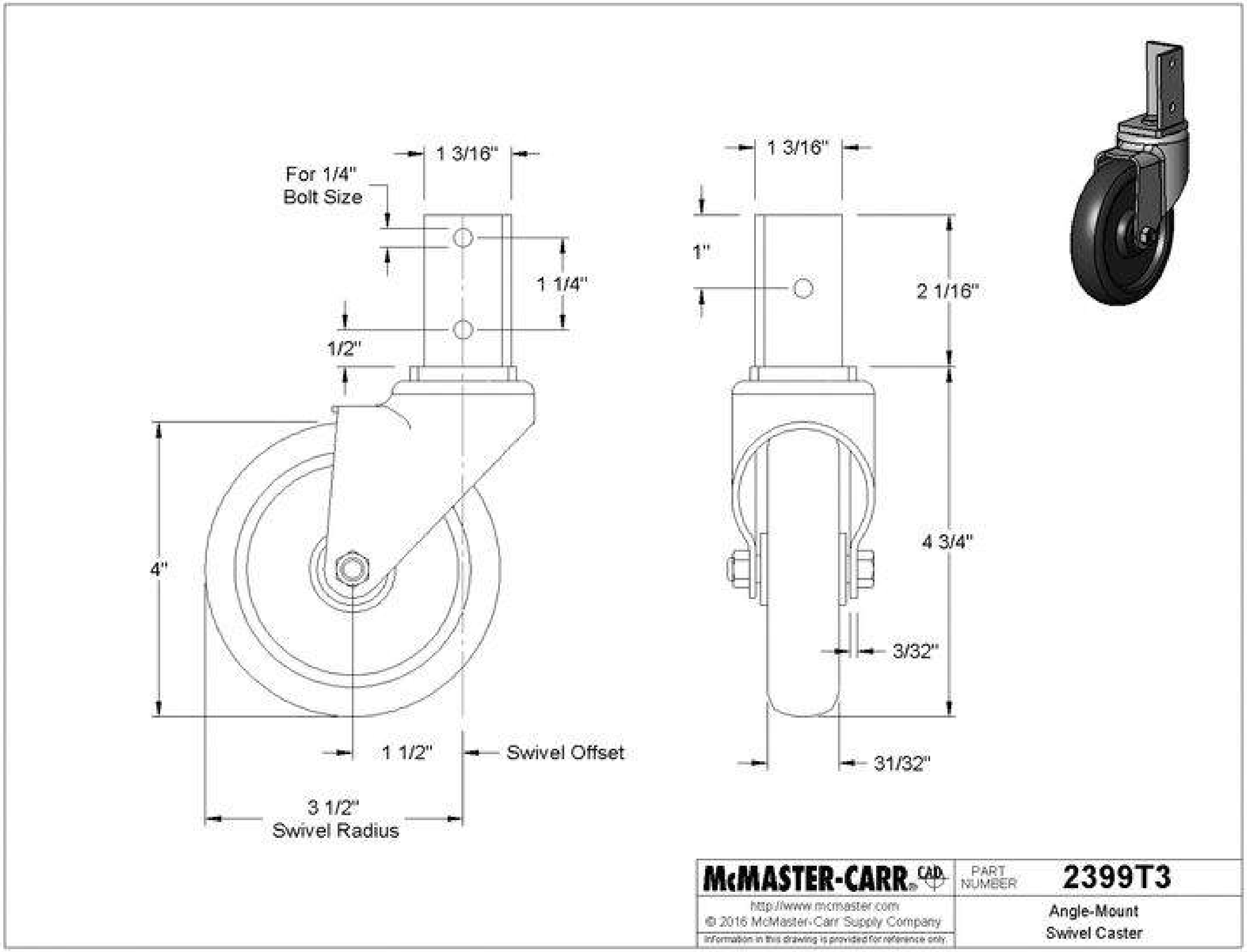


Figure D.5: Drawing 220 - Caster Assembly

Angle Mount Caster

4" x 31/32" Rubber Wheel, 110 lb Capacity

Each

ADD TO ORDER

In stock
$21.00 Each
2399T3

Wheel	
Diameter	4"
Width	31/32"
Mount Height	4 3/4"
Capacity Each	110 lbs.
Additional Specifications	Swivel
	Cushioned Black Rubber Wheels

A 90° angle bracket mounts into square tubing and can also be bolted to angle iron using three 1/4" bolts. Frame is zinc-plated steel.

Cushioned Rubber—Wheels are soft (80A durometer).

Figure D.6: Drawing 221 - Caster Specification Sheet

Figure D.7: Drawing 230 - Leveling Assembly

Material

Plastic and steel

Size

for 2"x2" square tube

for 1-1/2"x1-1/2" square tube

for 1-1/8"x1-1/8" square tube

for 13/16" square tube

for 1"x1" square tube

Color and finish

Black

Product features

Adjustable height

More details

This price is for FOUR pcs.

Figure D.8: Drawing 230A - Leveling Assembly Details

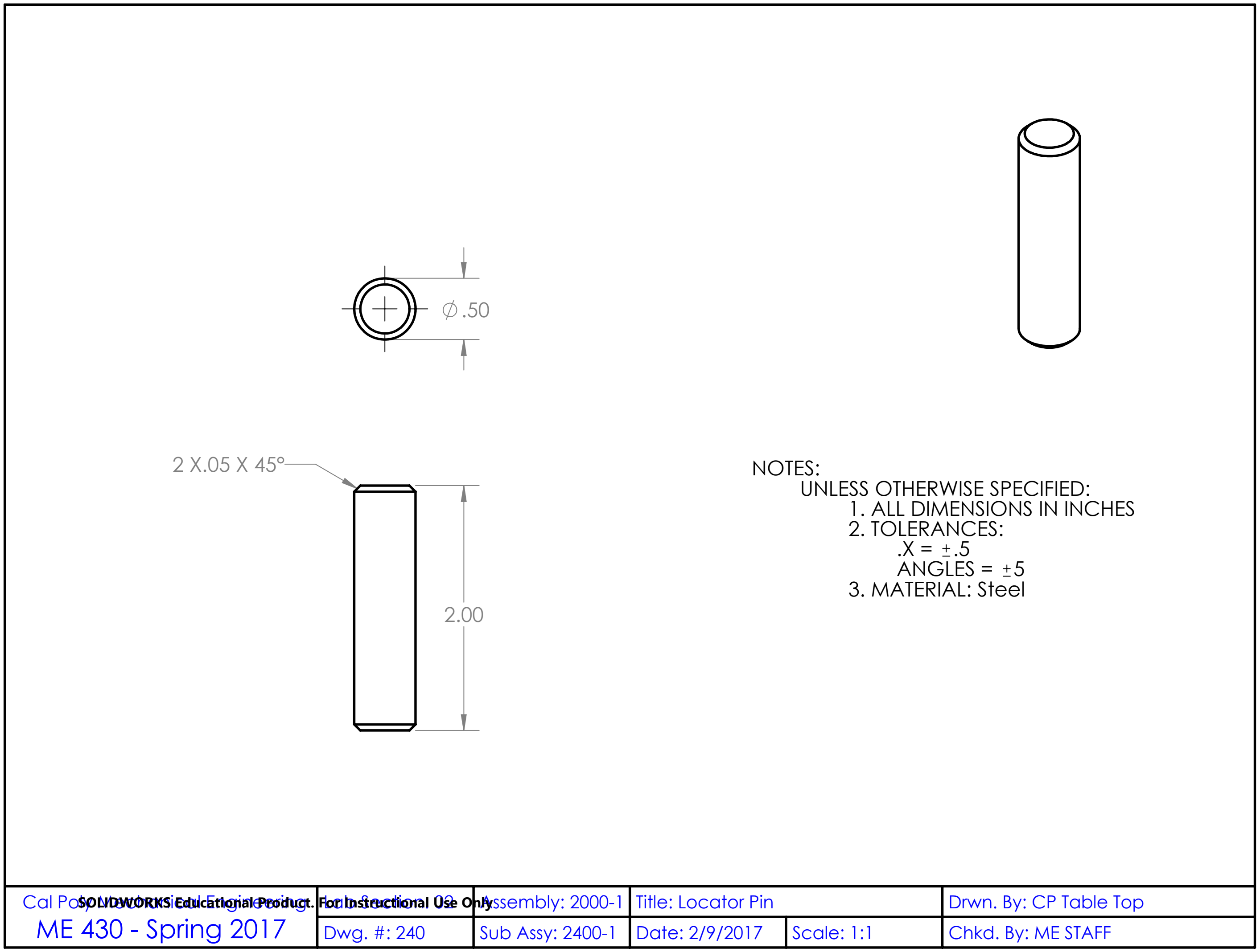


Figure D.9: Drawing 240 - Pin Drawing

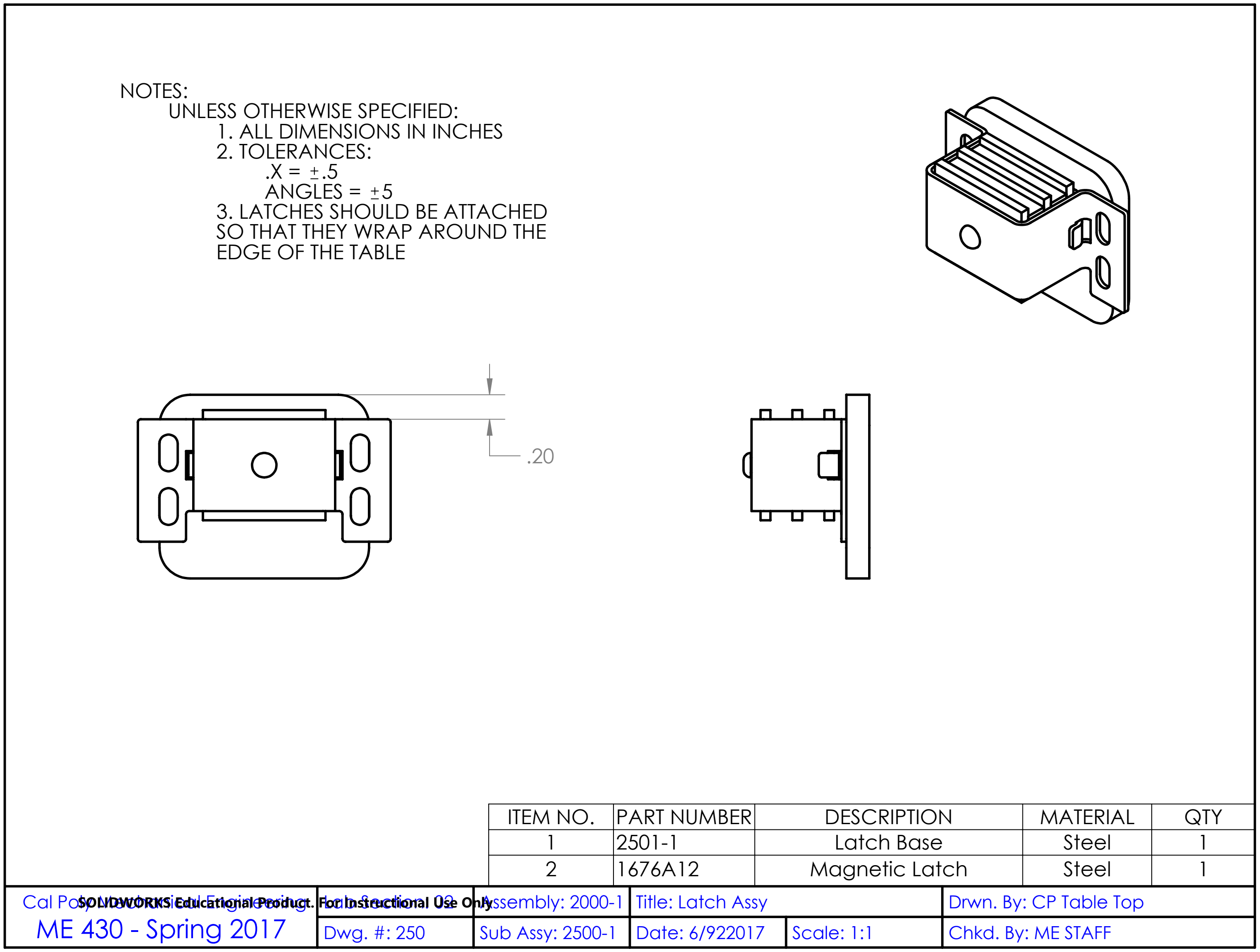


Figure D.10: Drawing 250 - Latch Assembly

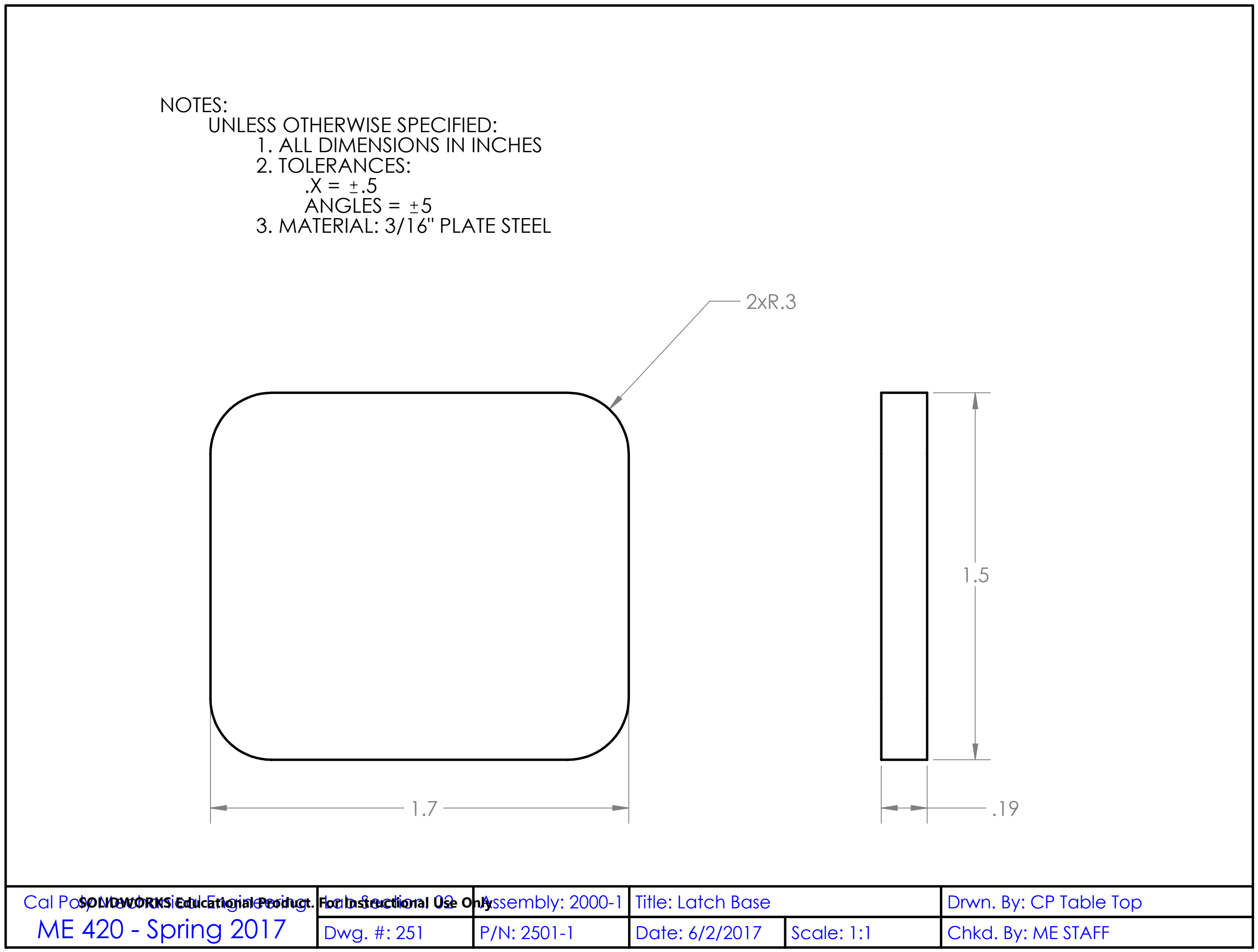


Figure D.11: Drawing 251 - Base Drawing

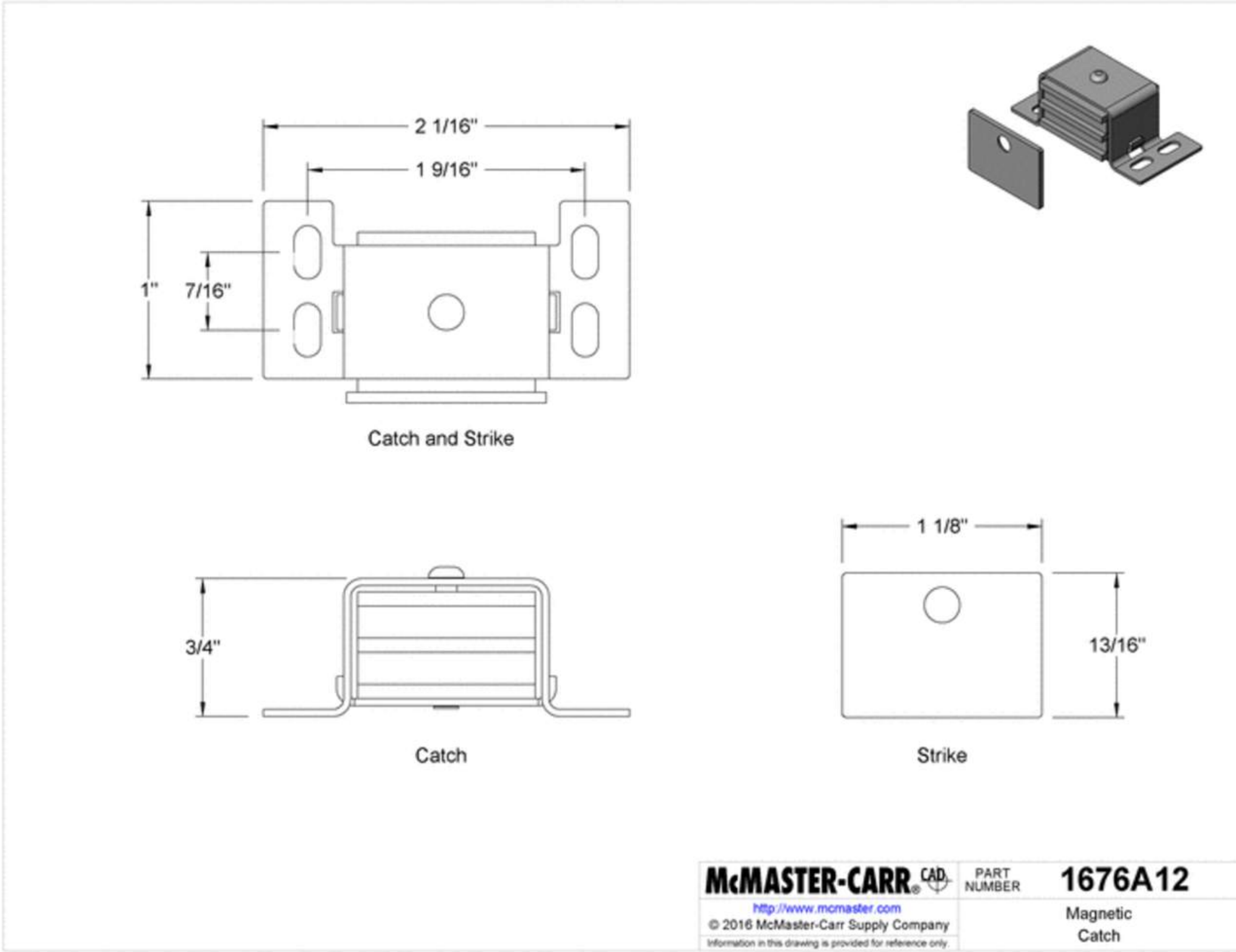
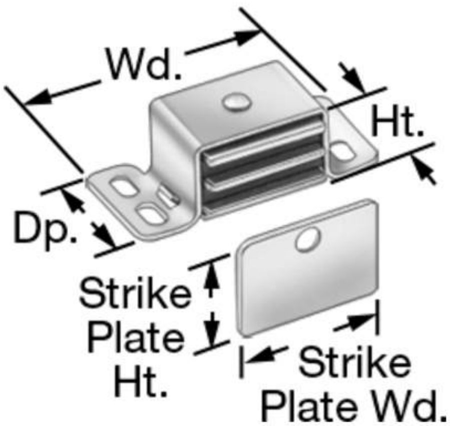


Figure D.12: Drawing 252 - Latch Drawing

Magnetic Latch

13 lbs. Maximum Pull Strength, Aluminum, 2-1/16" x 3/4" x 1"



Each

ADD TO ORDER

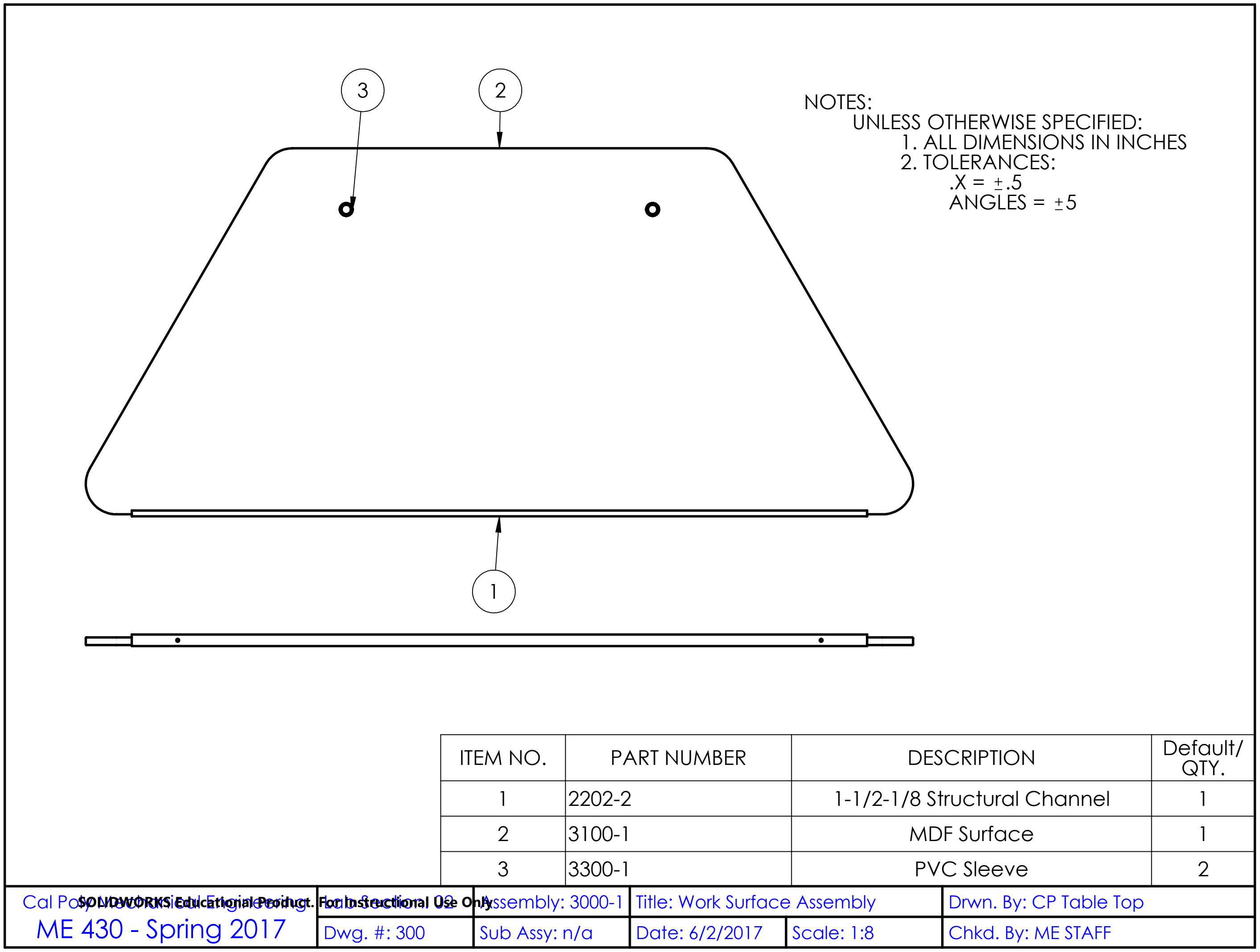
In stock
$2.77 Each
1676A12

Maximum Pull Strength	13 lbs.
Material	Aluminum
Appearance	Dull
Width	2 1/16"
Height	3/4"
Depth	1"
Mounting Hole Center-to-Center	7/16", 1 9/16"
Strike Plate	
Material	Steel
Width	1 1/8"
Height	13/16"
Type	Magnetic
Mounting Style	Surface
Mount Type	Screw On
Mounting Hardware Included	Yes
Push-to-Close Latch Type	Nonlocking
RoHS	Compliant

Magnets on the latch and strike plate meet to hold doors shut. These latches can often be found on audio/visual cabinets.

Note: Maximum pull-strength rating given is based on installation with the furnished strike plate; pull strength may be different based on your application.

Figure D.13: Drawing 253 - Latch Specification Sheet



ITEM NO.	PART NUMBER	DESCRIPTION	Default/ QTY.
1	2202-2	1-1/2-1/8 Structural Channel	1
2	3100-1	MDF Surface	1
3	3300-1	PVC Sleeve	2

Figure D.14: Drawing 300 - Work Surface Assembly

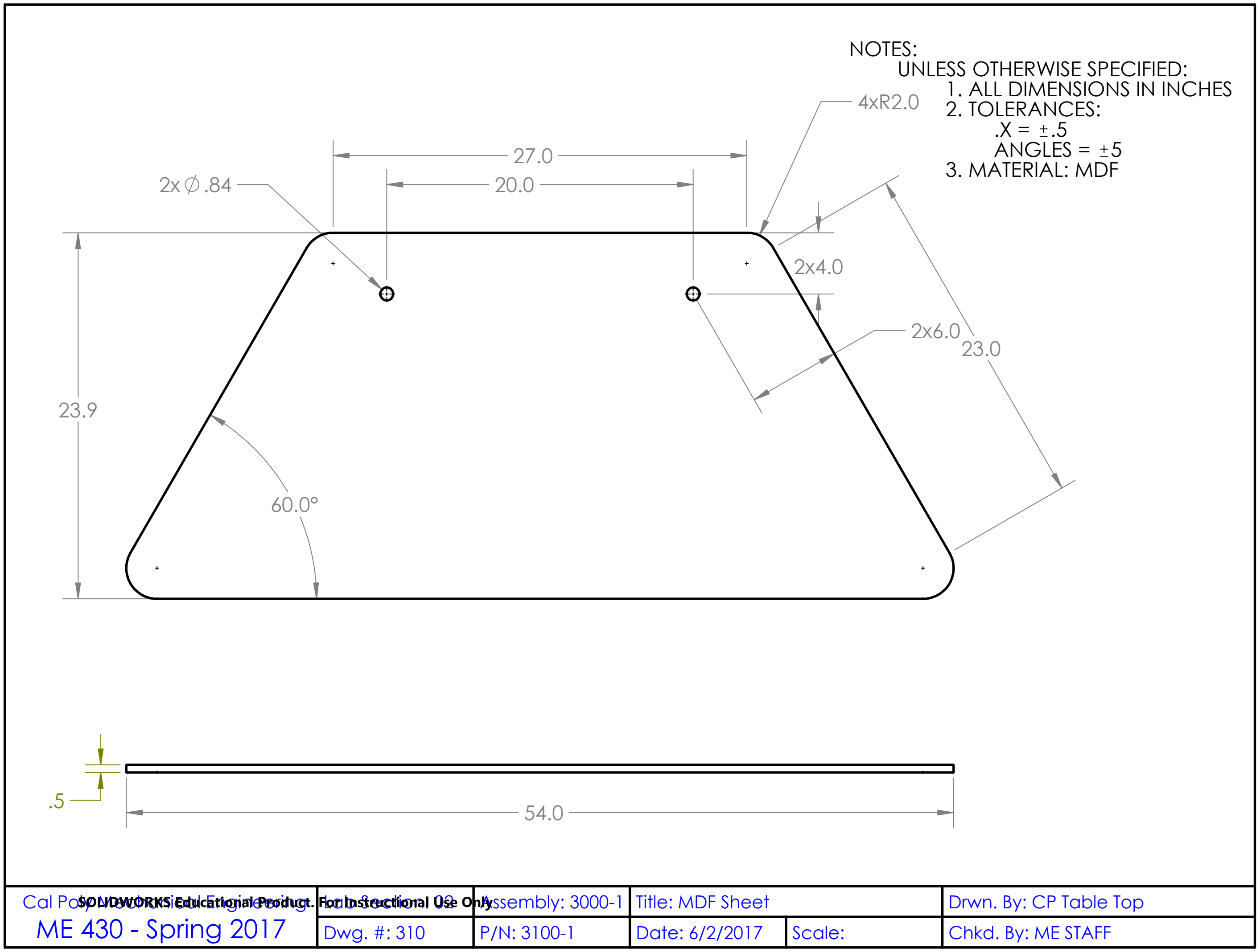


Figure D.15: Drawing 310 - MDF Surface Drawing

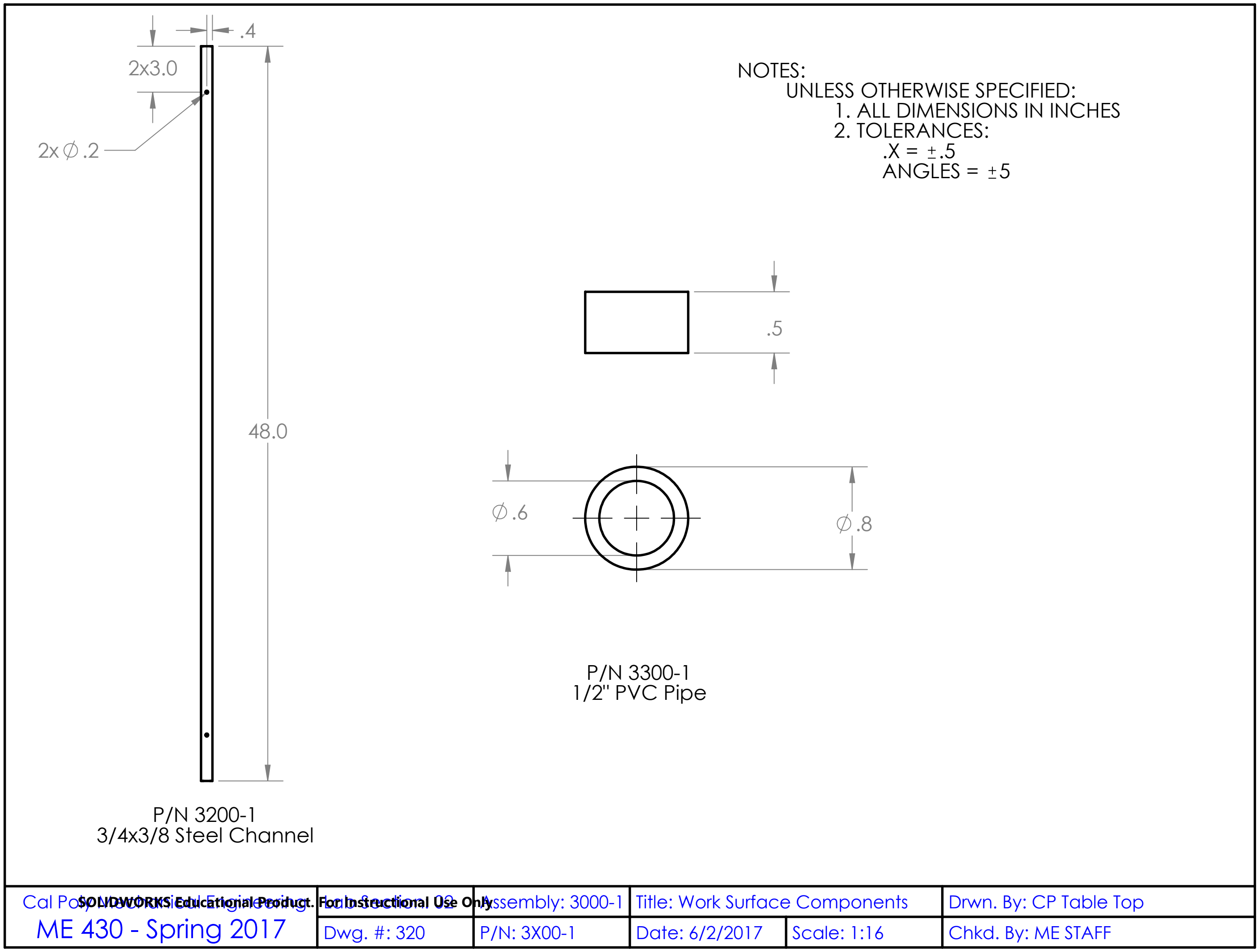


Figure D.16: Drawing 320 - Surface Components

Product Overview

Use the Rust-Oleum Specialty 27 oz. White Gloss Dry Erase Kit in offices, playrooms, children's rooms and more to create a dry-erase surface. This low-odor latex-based paint dries to a smooth, hard finish and is suitable for application on drywall, masonite, wood, cement and metal surfaces. This 27 oz. container covers up to 50 sq. ft.
California residents: see Proposition 65 information

- Great for offices, playrooms, children's rooms and more
- Latex-based formula is suitable for use on drywall, masonite, wood, cement and metal materials
- Gloss sheen
- 50 sq. ft.
- Creates a smooth, glossy finish for indoor use
- Writeable-erasable finish, allow to paint to dry three days before applying markers
- Easy to clean with soap and water

Info & Guides

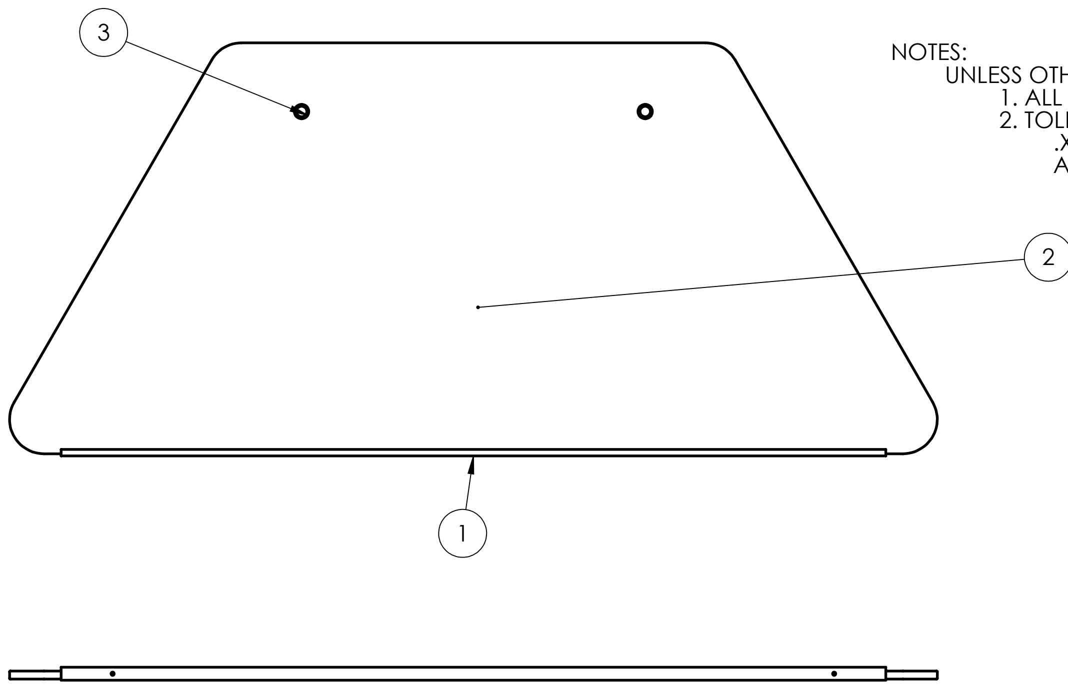
Instructions / Assembly

SDS

Use and Care Manual

You will need Adobe® Acrobat® Reader to view PDF documents. Download a free copy from the Adobe Web site.

Figure D.17: Drawing 330 - Dry-Erase Paint Specifications



NOTES:
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES:
.X = ±.5
ANGLES = ±5

ITEM NO.	PART NUMBER	DESCRIPTION	Formal/QTY.
1	2202-2	1-1/2-1/8 Structural Channel	1
2	4100-1	Birch Plywood Surface	1
3	3300-1	PVC Sleeve	2

Cal Poly Mechanical Engineering - Lab Section 02		Assembly: 4000-1	Title: Formal Surface Assembly		Drwn. By: CP Table Top
ME 430 - Spring 2017	Dwg. #: 400	Sub Assy: n/a	Date: 6/2/2017	Scale: 1:8	Chkd. By: ME STAFF

Figure D.18: Drawing 400 - Formal Surface Assembly

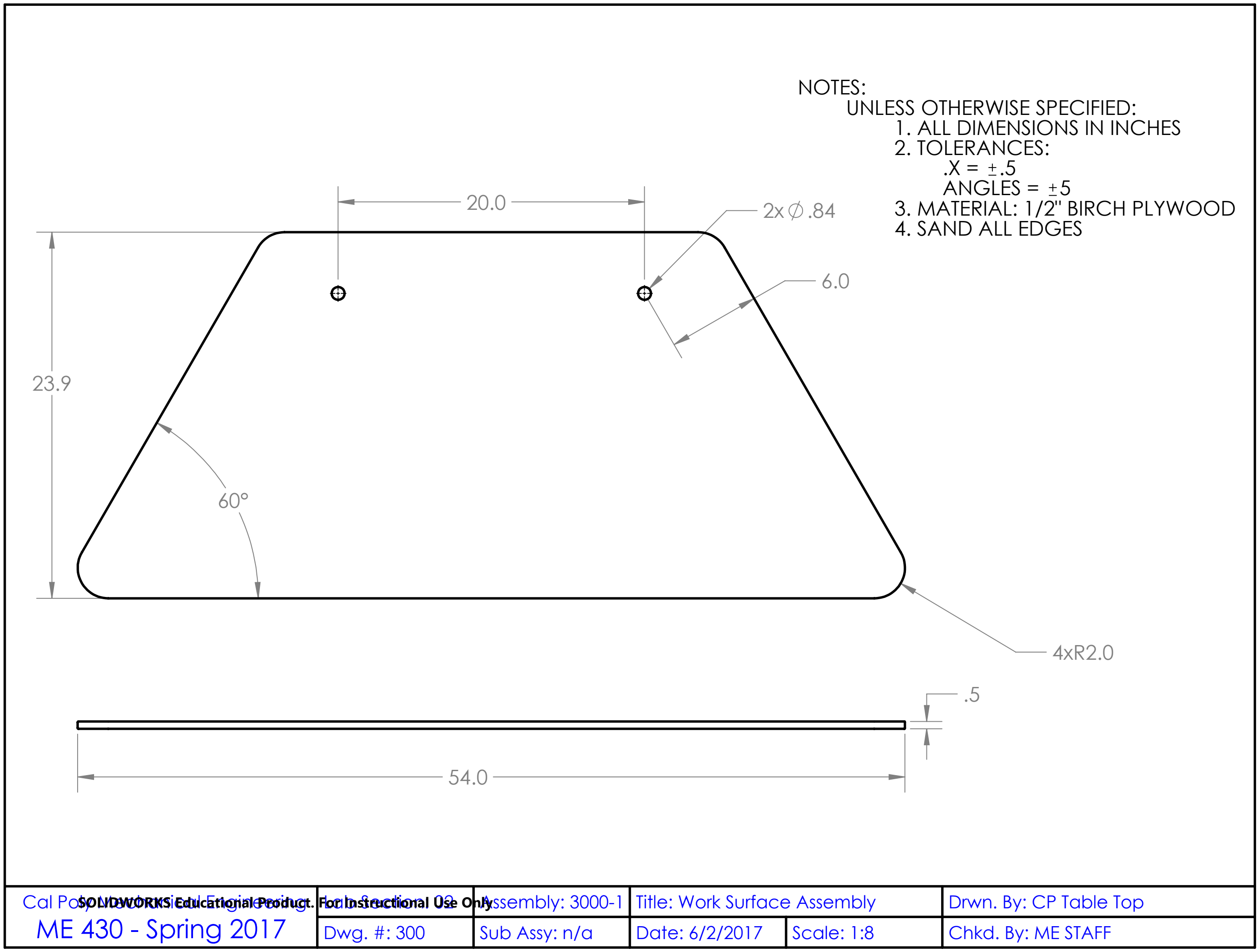


Figure D.19: Drawing 410 - Plywood Drawing

Specifications

Dimensions

Actual product Length (ft.)	4	Nominal Product Thickness (in.)	1/2
Actual product thickness (in.)	0.21	Nominal Product Width (ft.)	2
Actual product width (in.)	23.875	Product Depth (in.)	0.472
Nominal Product Length (ft.)	4	Product Height (in.)	47.875

Details

Plywood Type	Hardwood Plywood	Stainable/Paintable	Stainable & Paintable
Pressure Treated	No	Tongue and Groove	No

Warranty / Certifications

Manufacturer Warranty	See store for details		

Figure D.20: Drawing 411 - Plywood Specification Sheet

Product Overview

The Minwax 1 qt. Clear Semi-gloss Water-Based Oil-Modified Polyurethane adds a beautiful finishing touch to your interior projects. The polyurethane can be applied with a foam brush or a synthetic bristle brush and is formulated to clean up easily with warm water. One can provides enough polyurethane to cover approximately 125 sq. ft.
California residents: see Proposition 65 information

- Formulated for easy application with a synthetic bristle brush or foam brush
- Suitable for interior use
- 1-can covers up to 125 sq. ft.
- Cleans up with warm water
- Get the right stain for your project - click here for a buyer's guide
- Suitable for application on any interior wood surface
- Actual paint colors may vary from on-screen and printer representations
- 1-can covers 120 sq. ft.
- Online Price includes Paint Care fee in the following states: CA, CO, CT, MN, OR, RI, VT

Info & Guides

Installation Guide

Product Brochure

SDS

Use and Care Manual

You will need Adobe® Acrobat® Reader to view PDF documents. Download a free copy from the Adobe Web site.

Figure D.21: Drawing 420 - Laquer Specification Sheet

Carpeted Deck Panel Truck

Enlarge & Video

Move artwork, tables or plywood with ease.

- Padded surface for scratch-free loading and unloading.
- 11" space between uprights.
- Removable uprights fit any size load.
- Rugged steel supports handle any cargo.

MODEL NO.	DECK SIZE W x L	LOAD CAPACITY	DESCRIPTION	WHEEL TYPE	WT. (LBS.)	PRICE EACH 1	PRICE EACH 2+	ADD TO CART
H-3174	27 x 30"	1,000 lbs.	Carpeted	5" Polyurethane	75	$219	$209	1 ADD

SHIPS UNASSEMBLED VIA MOTOR FREIGHT

⊟ Additional Info ⊞ Parts ⊞ Email Page ⊞ Add to Favorites Request a Catalog

DIMENSIONS:
- Deck- Actual: 26 3/4 x 31"
- Height:
  - Overall: 40"
  - Uprights- From Top of Deck: 30 1/2"
  - Deck: 9 1/2"

REPLACEMENT CASTERS:
- 5" Polyurethane, Swivel: H-3173SWVL

COMPATIBLE CASTERS:
- 4" Polyolefin: H-2776
- 5" Polyurethane, Rigid: H-3173RIGID

Ships Via Motor Freight

Availability: In Stock
Unit Weight: 77 lbs.

Instructions

Catalog Page 393

Figure D.22: Drawing 500 - Cart Specification Sheet

E Bill of Materials

Table E.1: Top Level Bill of Materials

Assembly	P/N	Component	Drawing/Spec	Op Sheet	Weight [lb]	Qty	Cost	Total Cost w/ Tax
1000	1000-1	One Table, Two Surfaces	DWG	100	-	2		$250.32
2000	2000-1	Frame Assy	DWG	200	31.61	1	-	$176.15
3000	3000-1	Work Surface	ASSY	300	19.68	1	-	$61.74
4000	4000-1	Formal Surface	ASSY	400	9.30	1	-	$74.31
5000	5000-1	Cart	Spec	500	77	1	$219.00	$314.33

Table E.2: Frame Bill of Materials

P/N	Component	DWG/Spec	Op Sheet	Stock Description	Weight [lb]	Qty	Cost Per	Cost with Tax
2000-1	Frame Assy	DWG	200	-	31.61	1	-	$176.15
2100-1	Full Weld Assy	DWG	210	-	30.30	1	-	$114.27
2101-1	Upper Front Support	DWG	211	1.5" Rolled Steel	4.25	2	$2.57	$5.55
2102-1	Upper Side Support	DWG	211	1.5" Rolled Steel	4.26	4	$2.57	$11.10
2103-1	Back Leg	DWG	211	1" Rolled Steel	3.89	6	$1.95	$12.64
2104-1	Front Leg	DWG	211	1" Rolled Steel	3.47	5	$1.95	$10.53
2105-1	Lower Front Support	DWG	211	.75" Rolled Steel	0.95	2	$0.70	$1.51
2106-1	Lower Side Support	DWG	211	.75" Rolled Steel	0.94	4	$0.70	$3.02
2399T3	Caster Assy	Spec	220	4" Wheels	0.43	2	$21.00	$45.36
2300-1	Leveling Assy	Spec	230	-	0.07	2	$3.25	$7.02
2400-1	Pin	DWG	240	1/2" Pin		2	$0.38	$0.81
2500-1	Latch Assy	DWG	250	-	0.07	1	-	$8.68
2501-1	Latch Base	DWG	251	3/16" Plate Steel	0.14	2	$1.25	$2.50
6139A31	Latch	Spec	252	Magnetic Latch	0.01	2	$2.77	$5.54

Table E.3: Active Work Surface Bill of Materials

P/N	Component	DWG/Spec	Op Sheet	Stock Description	Weight [lb]	Qty	Cost Per	Total Cost
3000-1	Work Surface	ASSY	300	-	19.68	1	-	$61.74
3100-1	MDF Surface	DWG	310	MDF Sheet	55.30	1	$24.97	$26.97
3200-1	Channel Support	DWG	320	3/4" Steel Channel	0.63	16	$0.75	$12.96
3300-1	PVC Spacer	DWG	330	PVC Pipe	0.04	8	$0.03	$0.23
3400-1	Dry Erase Paint	Spec	340			1	19.98	$21.58

Table E.4: Formal Surface Bill of Materials

P/N	Component	DWG/Spec	Op Sheet	Stock Description	Weight [lb]	Qty	Cost Per	Total Cost
4000-1	Formal Surface	ASSY	400	-	9.30	1	-	$74.31
4100-1	Birch Plywood	DWG	410	Birch Plywood	8.66	1	$39.95	$43.15
3200-1	Channel Support	DWG	320	3/4" Steel Channel	0.63	16	$0.75	$12.96
3300-1	Press Fit Drill Bushings	Spec	330	PVC Pipe	0.04	8	$0.03	$0.23
4200-1	Varnish	Spec	420	Varnish	-	1	$17.97	$17.97

F Sourcing Details

Table F.1: Source List

Component	**Description**	**P/N**	**Supplier**
Square Tubing	1.5" Square Steel Tubing	2101-1	McCarthy Steel
Square Tubing	1.5" Square Steel Tubing	2102-1	McCarthy Steel
Square Tubing	1" Square Steel Tubing	2103-1	McCarthy Steel
Square Tubing	1" Square Steel Tubing	2104-1	McCarthy Steel
Square Tubing	.75" Square Steel Tubing	2105-1	McCarthy Steel
Square Tubing	.75" Square Steel Tubing	2106-1	McCarthy Steel
Latch Base	3/16" Plate Steel	2501-1	McCarthy Steel
Caster	4" Angle Mount Caster	2399T3	www.mcmaster.com
Nut	1/4" Nut		Miner's Ace
Bolt	1/4" Bolt		Miner's Ace
Leveler	Leveling Mount	6111K48	www.ebay.com
Pin	1/2" Pin	9739A31	Home Depot
Surface	1/2" MDF Sheet	3100-1	Home Depot
Surface	Birch Plywood	4100-1	Home Depot
Support Channel	3/4x3/8x1/8 Steel Channel	3200-1	Precision Machining
Bushing	PVC Pipe	3300-1	Home Depot
Bushing	.5312" ID-1/2" Bushing	8491A481	www.mcmaster.com
Edging	3/4" Rubber Edging	n/a	www.amazon.com
Dry Erase Paint	Dry Erase Paint	3400-1	Home Depot
Vernier	Minwax	4200-1	Home Depot

G Purchases

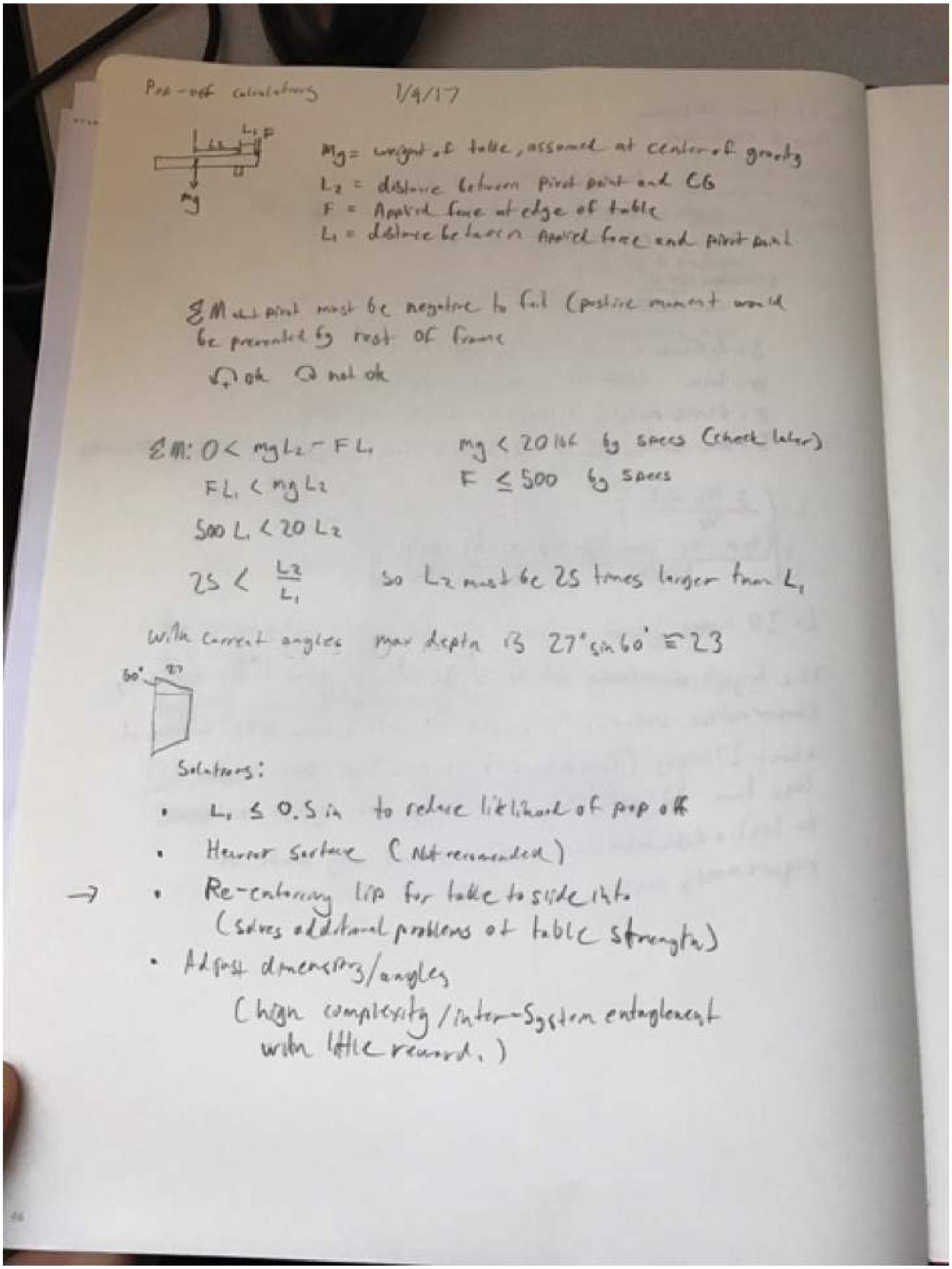
Table G.1: Purchased Components

Date	**Store**	**Item**	**Cost/Unit**	**Additional Charges**	**Number of Units**	**Total Item Cost**	**Running Total**	**Bill Total**
1/14	Home Depot	Hinge	$2.27	$0.00	3	$6.81	$6.81	$36.05
		2x3	$2.07	$0.02	2	$4.18	$10.99	
		OSB	$17.07	$0.17	1	$17.24	$28.23	
		Screws	$5.24	$0.00	1	$5.24	$33.47	
		Tax	-	-	-	$2.58	$36.05	
2/3	McCarthy Steel	1.5”	$2.57	$0.00	8	$20.56	$56.61	$61.63
		1”	$1.95	$0.00	14	$27.30	$83.91	
		.75”	$0.70	$0.00	8	$5.60	$89.51	
		Cut	$1.00	$0.00	4	$4.00	$93.51	
		Tax	-	-	-	$4.17	$97.68	
2/14	McMaster	Magnetic Latch	$2.77	$0.00	4	$11.08	$108.76	$137.76
		Bushing	$10.72	$0.00	4	$42.88	$151.64	
		Pin	$7.50	$0.00	2	$15.00	$166.64	
		Leveler	$5.79	$0.00	2	$11.58	$178.22	
		Caster	$21.00	$0.00	2	$42.00	$220.22	
		Tax	-	-	-	$8.89	$229.11	
		Shipping	$6.33	$0.00	1	$6.33	$235.44	
2/16	Miner’s	Nut/Bolt	$0.37	$0.00	6	$2.22	$237.66	$2.39
		Tax	-	-	-	$0.17	$237.83	
2/16	Home Depot	MDF	$11.95	$0.11	1	$12.06	$249.89	$31.26
		Shower Board	$9.99	$0.00	1	$9.99	$259.88	
		Titebond	$6.97	$0.00	1	$6.97	$266.85	
		Tax	-	-	-	$2.24	$269.09	
3/8	Precision Machining	Steel Channel	$15.00	$0.00	1	$15.00	$284.09	$15.00
4/6	eBay	Leveler	$13.00	$0.00	1	$13.00	$297.09	$13.00
4/6	Amazon	T-Molding	$45.00	$0.00	1	$45.00	$342.09	$45.00
4/11	Home Depot	MDF	$24.97	$0.00	1	$24.97	$367.06	$24.97
5/9	Home Depot	Sand Bags	$2.60	$0.00	7	19.61	$386.67	$21.02
		Tax	-	-	-	1.41	$388.08	

Table G.1: Purchased Components

Date	Store	Item	Cost/Unit	Additional Charges	Number of Units	Total Item Cost	Running Total	Bill Total
5/19	McCarthy Steel	1.5"	$2.57	$0.00	8	$20.56	$408.64	$61.52
		1"	$1.95	$0.00	14	$27.30	$435.94	
		.75"	$0.90	$0.00	8	$7.20	$443.14	
		3/16" Plate	$1.15	$0.00	2	$2.30	$445.44	
		Tax	-	-	-	$4.16	$449.60	
5/26	Home Depot	Paracord	$3.98	$0.00	1	$3.98	$453.58	$74.87
		MDF	$24.97	$0.24	1	$25.21	$478.79	
		Birch Plywood	$39.95	$0.39	1	$40.34	$519.13	
		Tax	-	-	-	$5.34	$524.47	
5/27	Home Depot	Minwax	$17.97	$0.35	1	$18.32	$542.79	$71.01
		PVC	$1.28	$0.00	1	$1.28	$544.07	
		Steel Rod	$6.78	$0.00	1	$6.78	$550.85	
		Brush	$6.97	$0.00	1	$6.97	$557.82	
		Rustoleum	$5.97	$0.00	1	$5.97	$563.79	
		Sandpaper	$7.97	$0.00	1	$7.97	$571.76	
		Sanding Tool	$9.97	$0.00	1	$9.97	$581.73	
		Sanding Block	$4.67	$0.00	1	$4.67	$586.40	
		Sanding Block	$3.97	$0.00	1	$3.97	$590.37	
		Tax	-	-	-	$5.11	$595.48	
5/29	Home Depot	Dry Erase Paint	$19.98	$0.35	1	$20.33	$615.81	$28.30
		Painters Tape	$5.93	$0.00	1	$5.93	$621.74	
		Tax	-	-	-	$2.04	$623.78	
5/31	Staples	Foam Board	$7.29	$0.00	1	$7.29	$631.07	$14.85
		Tape	$6.49	$0.00	1	$6.49	$637.56	
		Tax	-	-	-	$1.07	$638.63	
5/31	Staples	Tri-Fold	$9.29	$0.00	1	$9.29	$647.92	$10.01
		Tax	-	-	-	$0.72	$648.64	

H Hand Calculations


Pop-off calculations 1/4/17

mg = weight of table, assumed at center of gravity
L_2 = distance between pivot point and CG
F = Applied force at edge of table
L_1 = distance between applied force and pivot point

ΣM about pivot must be negative to fail (positive moment would be prevented by rest of frame

ok not ok

$\Sigma M: 0 < mgL_2 - FL_1$ $mg < 20$ lbf by specs (check later)
$FL_1 < mgL_2$ $F \leq 500$ by specs
$500 L_1 < 20 L_2$
$25 < \frac{L_2}{L_1}$ so L_2 must be 25 times larger than L_1

With current angles max depth is $27" \sin 60° \cong 23$

60° 27

Solutions:
- $L_1 \leq 0.5$ in to reduce likelihood of pop off
- Heavier surface (Not recommended)
- → Re-entering lip for table to slide into (solves additional problems of table strength)
- Adjust dimensions/angles (high complexity / inter-system entanglement with little reward.)

Figure H.1: Hand calculations: tipping concerns.

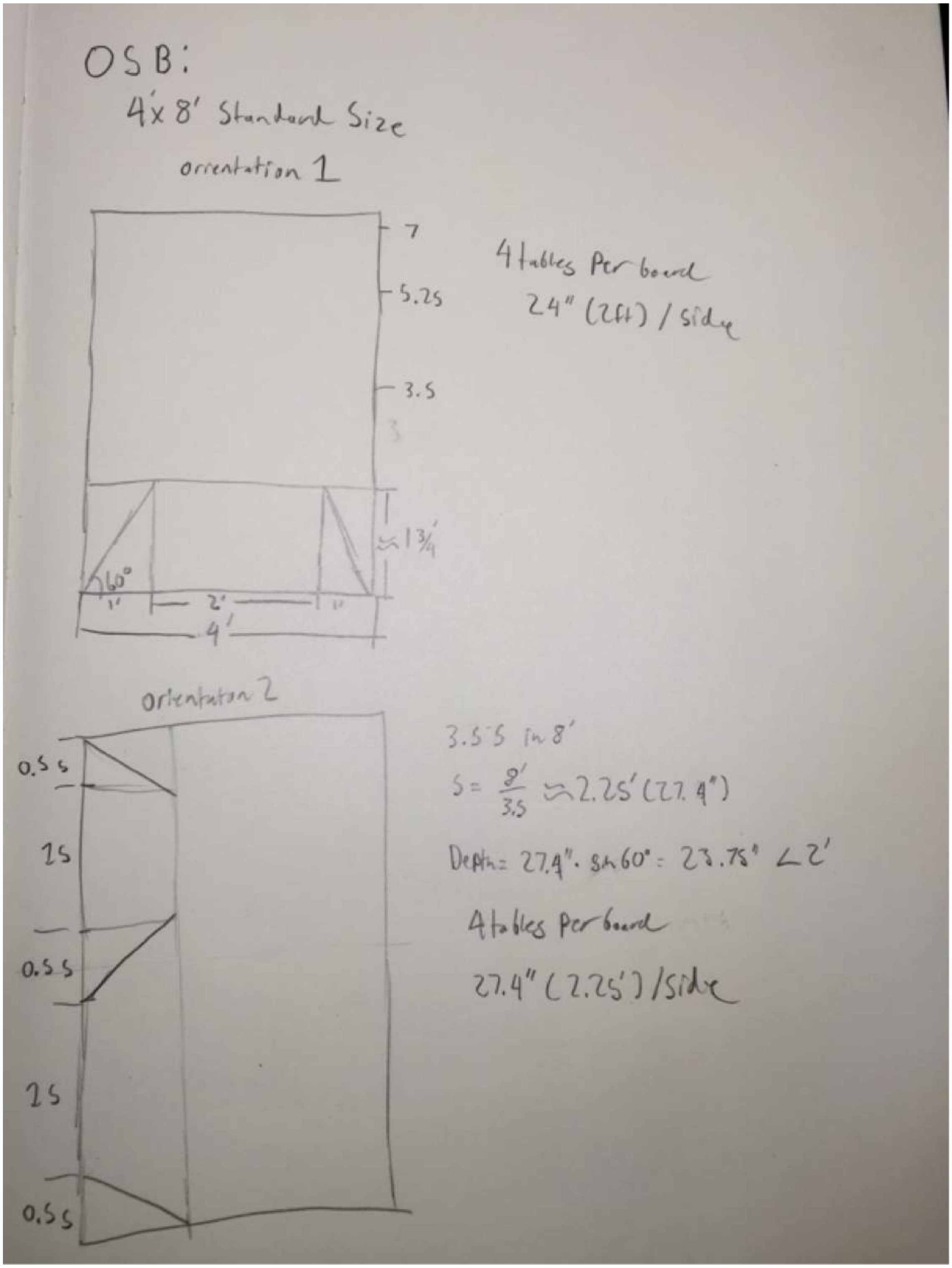
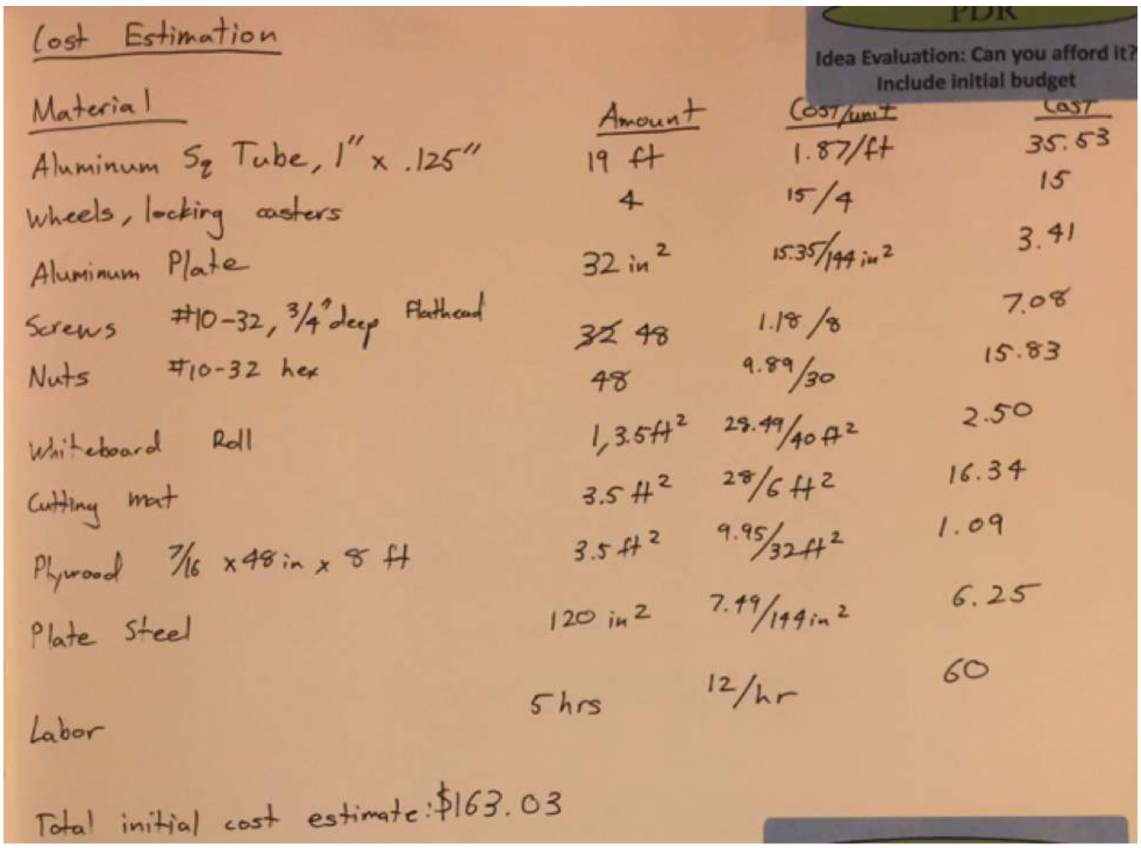


Figure H.2: Hand calculations: Sizing.



Cost Estimation

Material	Amount	Cost/unit	Cost
Aluminum Sq Tube, 1" x .125"	19 ft	1.87/ft	35.53
Wheels, locking casters	4	15/4	15
Aluminum Plate	32 in^2	15.35/144 in^2	3.41
Screws #10-32, 3/4" deep Flathead	~~32~~ 48	1.18/8	7.08
Nuts #10-32 hex	48	9.89/30	15.83
Whiteboard Roll	1, 3.5 ft^2	28.49/40 ft^2	2.50
Cutting mat	3.5 ft^2	28/6 ft^2	16.34
Plywood 7/16 x 48 in x 8 ft	3.5 ft^2	9.95/32 ft^2	1.09
Plate Steel	120 in^2	7.49/144 in^2	6.25
Labor	5 hrs	12/hr	60

Total initial cost estimate: $163.03

Figure H.3: Hand calculations: Preliminary Budget.

I Design Validation Calculations

I.1 Compressive Failure of Legs

Governing Equation:

$$\delta = \frac{P*L}{A*E}$$

δ is the displacement of the material, which must be less than 1/8th of an inch to meet our requirements.

P is the expected load, normally the table will experience 500 lbf distributed over all four legs, however we will verify the extreme loading situation of 500 lbf concentrated on one leg.

L is the length of the member undergoing the load. Our conservative estimate is the maximum leg length of 36 in, which assumes none of the table's height comes from the surface or any wheels.

A is the cross sectional area of the member. For a hollow square tube the area can be calculated by:

$$A = s^2 - (s - 2 * t)^2$$

Where s is the side length of the square tubing, and t is the wall thickness of the square tubing.

$$A = 1in^2 - (1in - 2 * \frac{1}{8}in)^2$$

$$A = .4375in^2$$

E is the elastic modulus of the material, which for steel is 30,000 ksi.

$$\delta = \frac{500lbf*36in}{.4275in^2*30000ksi} * [\frac{1ksi}{1000\frac{lbf}{in^2}}]$$

$$\delta = .00137in$$

The factor of safety can be calculated as:

$$FS = \frac{Desired}{Calculated}$$

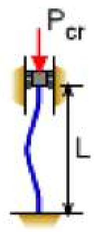
$$FS = \frac{.125in}{.00137in}$$

$$FS = 91.1$$

I.2 Buckling Failure of Legs

Due to welds securing both ends of the vertical beams, we will model the system as fixed-fixed.

Governing Equation:



$$P_cr = \frac{\pi^2 * E * I}{L_e^2}$$

P_cr is the maximum loading allowed before buckling is imminent.

E is the elastic modulus of the material, which for steel is 30,000 ksi.

I is the second moment of area of the member. For a square tube this can be calculated by:

$$I = \frac{1in^4 - (s - 2 * t)^4}{12}$$

Where s is the side length of the square tubing, and t is the wall thickness of the square tubing.

$$I = \frac{1in^4 - (s - 2 * t)^4}{12}$$

$$I = .05697in^4$$

L_e is the equivalent length, which is determined by how the ends of the beam are attached. For a fixed-fixed system:

$$L_e = .5 * L$$

Where L is the length of the member undergoing the load. Our conservative estimate is the maximum leg length of 36 in, which assumes none of the table's height comes from the surface or any wheels.

$$P_cr = \frac{\pi^2 * 30000ksi * .05697in^4}{(.5 * 36in)^2} * [\frac{1ksi}{1000\frac{lbf}{in^2}}]$$

$$P_cr = 52059lbf$$

The factor of safety can be calculated as:

$$FS = \frac{Maximum}{Allowable}$$

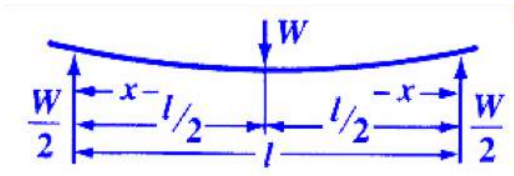
$$FS = \frac{52059lbf}{500lbf}$$

$$FS = 104.1$$

I.3 Deflection of Frame

Model the system as a beam fixed at both ends due to welds with a centrally located point load to remain conservative.

Governing Equation:



$$y = \frac{W*x}{48*E*I} * (3*L^2 - 4*x^2)$$

P is the expected load, normally the table will experience 500 lbf distributed over all four legs, however we will verify the extreme loading situation of 500 lbf concentrated at the center of a beam.

L is the length of the member undergoing the load. Our conservative estimate is the frame dimension of 24 in.

l is the location along the beam that the deflection is to be calculated at. For our situation X is halfway between the two supports, at $X = L/2 = 12$in.

E is the elastic modulus of the material, which for steel is 30,000 ksi.

I is the second moment of area of the member. For a square tube this can be calculated by:

$$I = \frac{1in^4 - (s-2*t)^4}{12}$$

Where s is the side length of the square tubing, and t is the wall thickness of the square tubing.

$$I = \frac{1.5in^4 - (1.5-2*\frac{1}{8}in)^4}{12}$$

$$I = .2184in^4$$

$$y == \frac{500lbf*12in}{48*30000ksi*.2184in^4} * (3*(24in)^2 - 4*(12in)^2)$$

$$y = .02198lbf$$

The factor of safety can be calculated as:

$$FS = \frac{Allowable}{Calculated}$$

$$FS = \frac{.125in}{.02198in}$$

$$FS = 5.69$$

I.4 Weld Strength: Transverse Loading

(Compression of Upper Frame)

Governing Equation:

$$\sigma_{all} = \frac{P}{A}$$

P is the loading experienced by the weld, which is no more than the 200 lbf transverse loading designed for.

A is the weld area which is calculated as shown below.

$$A = t * P_{mid}$$

t is the thickness of the material (and therefore the weld for a butt joint) which is 1/8 inch.

P_{mid} is the midline perimeter of the weld calculated for a square tube as shown below. Note that the actual perimeter would be longer for tubes cut at an angle.

$$P_{mid} = 4 * (L - t)$$

L is the length of the side of the square tubing. For the upper rail this is 1.5 inches.

$$P_{mid} = 4 * (1.5in - .125in)$$

$$P_{mid} = 5.5in$$

$$A = .125in * 5.5in$$

$$A = .6875in$$

$$\sigma_{all} = \frac{200lbf}{.6875in^2}$$

$$\sigma_{all} = 290.9psi$$

$$\sigma_{all} = .60 * \sigma_{ut}$$

$$\sigma_{ut} = \frac{sigma_{all}}{.60}$$

$$\sigma_{ut} = \frac{290.9psi}{.60}$$

$$\sigma_{ut} = 484.8psi$$

So, as long as the ultimate strength of our filler material is greater than 500psi, then our welds should hold. Luckily steel has a strength on the order of 30,000ksi, meaning the welds should be more than strong enough to withstand our loading assuming complete penetration.

I.5 Weld Strength: Shear Loading

(Shear at top of legs)

Governing Equation:

$$\tau_{all} = \frac{P}{A}$$

Where P is still the 200lbf transverse load, but A has a new value based on the 1in square tubing used for the legs.

$$\tau_{all} = \frac{200lbf}{.4375in^2}$$

$$\tau_{all} = 457.1psi$$

For butt or fillet welds in shear:

$$\tau_{all} = .30 * \sigma_{ut}$$

$$\sigma_{ut} = \frac{\tau_{all}}{.30}$$

$$\sigma_{ut} = \frac{457.1psi}{.30}$$

$$\sigma_{ut} = 1523.8psi$$

Note that the ultimate strength is still well below the strength of steel.

I.6 Bolt Calculations

(Bearing in all bolts)

Governing Equation:

$$\sigma = \frac{F}{2*t*d} = \frac{S_y}{N_d}$$

F is the load that the bolt will have to bear. For our calculations, we assume that the maximum load will be 250 lbs, which is half of the maximum overall load as each side of the bolt should take half of the overall load (assuming just one bolt).

t is the wall thickness of the steel tubing, which contributes to the area over which the load is applied to the bolt. For our joints the wall thickness will be 1/8 inch.

d is the diameter of the bolt, which we will assume to be 1/4inch as an initial estimate to maximize area while reducing interference with the tube walls.

S_y is the yield strength of the bolt.

N_d is the factor of safety, assumed to be 1 for now. Solving for S_y:

$$S_y = \frac{F*N_d}{2*t*d}$$

$$S_y = \frac{250lb*1}{2*.125in*.25in}$$

$$S_y = 4ksi \text{ (required for bolt)}$$

Bearing in members requires the same calculation, and results in the same yield strength requirement, but applied to the member instead of the bolt.

$$S_y = 4ksi \text{ (required for member)}$$

Shear of bolts (assuming no threads in active zone):

$$\tau = \frac{F}{\pi*d^2} = .577\frac{S_y}{N_d}$$

$$S_y = \frac{F*N_d}{\pi*d^2*.577}$$

$$S_y = \frac{250lbf*1}{\pi*(.25in)^2*.577}$$

$$S_y = 2.2ksi \text{ (required for bolt)}$$

Shear of bolts (assuming threads in active zone):

$$\tau = \frac{F}{4*A_r} = .577\frac{S_y}{N_d}$$

Where A_r is the active radius of the bolt in the threaded region. For a 1/4 inch bolt A_r is 0.0318 in2.

Solving for S_y:

$$S_y = \frac{F*N_d}{4*A_r*.577}$$

$$S_y = \frac{250lbf*1}{4*.0318in^2*.577}$$

$$S_y = 3.4ksi \text{ (required for bolt)}$$

$$\tau = \frac{F}{A*t} = \frac{S_y}{N_d}$$

Where A is the length of material in the same axis as the bolt hole. For a conservative estimate assuming only the walls of the tubing will bear the load:

$$A = 1in - 2*.125in - .25in$$

A = 0.5 inches, removing 2*0.125in for the wall thickness on either end, and removing 0.25in for the hole.

Solving for S_y:

$$S_y = \frac{F*N_d}{A*t}$$

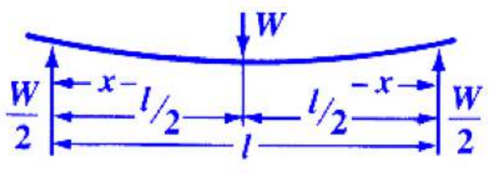
$$S_y = \frac{250lbf*1}{.5in*.125in}$$

$$S_y = 4ksi \text{ (required for member)}$$

I.7 Surface Deflection

Model the system as a beam fixed at both ends due to welds with a centrally located point load to remain conservative.

Governing Equation:



$$y = \frac{W*x}{48*E*I}(3*L^2 - 4*x^2)$$

P is the expected load, normally the table will experience 500 lbf distributed over all four legs, however we will verify the extreme loading situation of 500 lbf concentrated at the center of a beam.

L is the length of the member undergoing the load. Our conservative estimate is the unsupported surface length of 54 in.

X is the location along the beam that the deflection is to be calculated at. For our situation X is halfway between the two supports, at X=L/2=27 in.

E is the elastic modulus of the material, which for MFD is 580 ksi.

I is the second moment of area of the member. For a solid rectangle this can be calculated by:

$$I = \frac{b*h^3}{12}$$

Where b is the width of the surface, and h is the thickness of the surface.

$$I = \frac{24in*\cos(30)*(.5in)^3}{12}$$

$$I = .2165in^4$$

$$y = \frac{500lbf*27in}{48*580ksi*.2165in^4}(3*(54in)^2 - 4*(27in)^2)*[\frac{1ksi}{1000\frac{lbf}{in^2}}]$$

$$y = 13.1in$$

Although our calculations are very conservative, a deflection of 13.1 inches is much greater than allowed by our specifications. Additional reinforcement is required. Assuming an aluminum reinforcement channel takes most of the loading, the equation can be reused with a new E of 10,000ksi for aluminum, and a new I for a channel calculated online as 0.012in4.

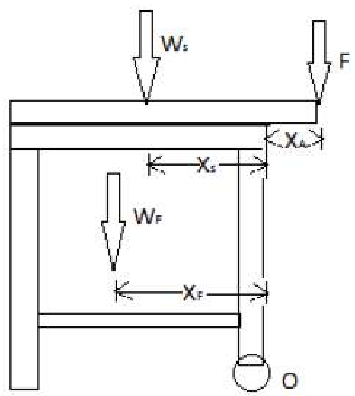
$$y = \frac{500lbf*27in}{48*580ksi*.2165in^4}(3*(54in)^2 - 4*(27in)^2)*[\frac{1ksi}{1000\frac{lbf}{in^2}}]$$

$$y = 13.67in$$

Although not completely within our specifications, use of an aluminum channel will be tested, as our modeling made many conservative assumptions. In reality, the full load will be distributed between both steel and MDF, and the support on the "front" side of the table will reduce the loading that acts upon the unsupported side. Additionally analysis that is more rigorous will be performed using software modeling.

I.8 Tipping Calculations

Governing Equation:



$$\Sigma M = 0$$

From the diagram:

$$\Sigma M_O : 0 = W_s * X_S + W_F * X_F - F * X_A$$

Where the sum of the moments is calculated around the front wheels, and the loads and dimensions are shown in the diagram above.

W_S is the weight of the surface, currently measured at 25lbf.

X_S is the distance between the center of gravity of the surface, and the front wheel of the frame, currently estimated at 6inches.

W_F is the weight of the frame, currently measured at 35lbf.

X_F is the distance between the center of gravity of the surface, and the front wheel of the frame, currently estimated at 7.44 inches.

X_A is the distance between the applied loading and the front wheel of the frame, currently modeled as 3 inches.

Solve for F to determine the allowable load before tipping will occur.

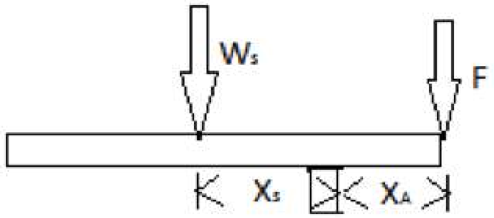
$$F = \frac{W_S * X_S + W_F * X_F}{X_A}$$

$$F = \frac{25lbf * 6in + 35lbf * 7.44in}{3in}$$

$$F = 136.8lbf$$

I.9 Pop Off

Governing Equation:



$$\Sigma M_O : 0 = W_S * X_S - F * X_A$$

Where the sum of the moments is calculated around the front rail, and the loads and dimensions are shown in the diagram above.

W_S is the weight of the surface, currently measured at 25lbf.

X_S is the distance between the center of gravity of the surface, and the front rail of the frame, currently estimated at 6inches.

X_A is the distance between the applied loading and the front rail of the frame, currently modeled as 3 inches.

Solve for F to determine the allowable load before pop off will occur.

$$F = \frac{W_S * X_S}{X_A}$$

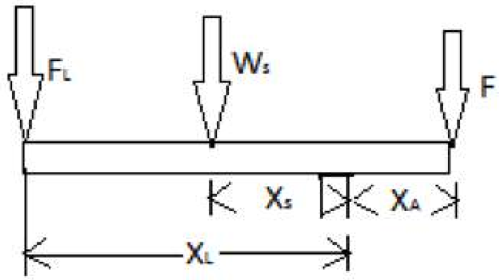
$$F = \frac{25lbf * 6in}{3in}$$

$$F = 50lbf$$

The surface will pop off after an applied load of 40lbf under the given geometry and lack of additional support.

I.10 Pop Off with a Latch

Governing Equation:



$$\Sigma M_O : 0 = W_S * X_S + F_L * X_L - F * X_A$$

F_L is the rated loading of the latches we intend to use, which is currently specified at 60lbf each, or a total of 120lbf for both latches.

X_L is the distance between the latch and the front rail of the frame, which is currently modeled as 20inches.

Solve for F to determine the allowable load before pop off will occur.

$$F = \frac{W_S * X_S + F_L * X_L}{X_A}$$

$$F = \frac{25lbf * 6in + 120lbf * 20in}{3in}$$

$$F = 850lbf$$

With latches we are much more confident in our ability to prevent pop-off.

J Design Hazard Checklist

DESIGN HAZARD CHECKLIST

Team: 56: Cal Poly Worktable Advisor: 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 any part of the electrical systems not be grounded?
☐	☒	9. Will there be any large batteries or electrical voltage in the system above 40 V?
☐	☒	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. Can 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, add (1) a complete description, (2) a list of corrective actions to be taken, and (3) date to be completed on the reverse side.

Description of Hazard	**Planned Corrective Action**	**Planned Date**	**Actual Date**
Pinch points will likely occur at the interface between the surface and the frame.	By making the frame smaller than the surface, the location of this interface should be moved away from where user hands will be, reducing the likelihood of pinching occurring. Additionally by ensuring the surface is as light as possible, damage caused by this pinch point should be minimized.		
The surface being popped off by a moment could cause the surface to fall on and injure a user.	Latches will be placed at the "open end" of the trapezoid to secure the surface against any moments and prevent "pop-off" from occurring. There should be no moment arm to "pop-off" the surface from the opposite side. Additionally by ensuring the surface is as light as possible, damage caused by a falling surface should be minimized.		
A moment placed on the surface could cause the whole table to flip over and injure a user.	Three partial solutions combined should reduce this hazard: By increasing the weight of the frame, there will be a larger moment acting against the tipping of the table. Decreasing the moment arm that an external load can be applied over, should reduce the likelihood that an applied force will flip the table. Making the frame larger should increase the moment arm for the weight, reducing the likelihood of tipping.		
Welds or cut ends of the frame could be sharp.	During manufacturing care will be taken to ensure that either the welds are smooth, or that any sharp edges are ground or filed down. Additionally a protective coating should work to make the surface smooth.		
Users could use the table in an unsafe manner by standing on the surface or otherwise loading the table inappropriately.	Care has been taken to overdesign the table to prevent failure from users climbing on the table. The frame is strong enough to withstand this loading, but the table still may tip if loaded in extreme ways.		

K Operator's Manual

K.1 Table Set Up

1. Roll frame to desired location.

   * To roll, lift the back legs of the table so that the table can be maneuvered using the casters on the front two legs.

2. Once frame is in desired location, consider adjusting levels on the back feet so that the top of the frame is level with the ground.
3. Locate desired surface from within a storage location.
4. Lift surface and place over the pins on the table.

   * Active design surfaces weight upwards of 20 pounds, lift carefully to avoid personal harm.

5. Locate holes on the surface over the pins on the frame.
6. Lower long back edge of the surface so the back channel activates the magnetic latches.
7. Use table as table.

K.2 Use of Table

- Do not lean on the table
- Have caution when placing large loads on the free hanging edge of the table.
- Have caution when applying point loads to the front corners of the table as the table may detach from its latches.

K.3 Table Take Down

1. Lift surface off of front or back edge so that the pins exit the holes or the magnetic latch detaches from the channel.

   * This may require some force.

2. Lift the entire surface off of the frame.

3. Place surface back in its storage location.
4. Lift surface and place over the pins on the table.

   * Active design surfaces weight upwards of 20 pounds, lift carefully to avoid personal harm.
5. Roll frame to storage location.

   * To roll, lift the back legs of the table so that the table can be maneuvered using the casters on the front two legs.
6. Nest frame with others for most efficient storage.

L Design Verification Plan and Report

DVP&R Assembly

Report Date	6/4/2017		Sponsor	Harding					Component/Assembly		1000	REPORTING ENGINEER: Kelsey		
TEST PLAN											**TEST REPORT**			
Item No	Specification or Clause Reference [1]	Test Description [2]	Acceptance Criteria [3]	Equipment Required	Test Responsibility [4]	Test Stage [5]	SAMPLES TESTED		TIMING		TEST RESULTS			NOTES
							Quantity	Type [6]	Start date	Finish date	Test Result [7]	Quantity Pass	Quantity Fail	
1	Table collapses under loading	Load table until collapse	500 lb even distribution	500 lb weights	Kelsey	Complete	1	Deflection	5/4/2017	5/9/2017	9/16 deflection	0	1	
2	Table tips under loading	Load corner until collapse or tip	200 lb point load	200 lb weights	Kelsey	Complete	2	Deflection	5/4/2017	5/9/2017	1.5 in deflection, no tip or pop off	2	1	
3	Table wobbles under loading	Shake table (eraser test)	1/8 in	A clay cone, a kitchenaid mixer	Kelsey	Complete	1	Deflection	6/4	6/4/2017	Violent Shaking	0	1	
4	Table falls apart	Get creative. Try to break the thing	Doesn't fall apart under loading conditions	Determined humans		Complete	2	Overall	5/4/2017	6/4/2017	Strong table	1	0	Through standard use of table
5	Table is hard to line up	Attempt to place surface onto frame (time this)	<60s line up	Frame and surface	Kelsey	Complete	2	Surface and Frame	4/28/2017	4/28/2017	Go	1	1	Completed without bushings. No official timing taken
6	Surface gets stuck on pins	Attempt ot remove surface from frame	<30s removal	Frame and surface	Kelsey	Complete	2	Surface and Frame	4/28/2017	4/28/2017	Go	1	1	Completed. Timing listed in test sheets
7	Wheels get stuck	Test rolling resistance of wheels	Rolls 5 ft in single push	Full table and different types of flooring	Kelsey	Complete	1	Surface and Frame	6/3/2017	6/3/2017	No Go	0	1	Table does not roll when pushed
8	Human loading	People sitting on the table to test classroom situations	Table deforms or moves under this loading	Full table and multiple people	Kelsey/Drew	Complete	2	Surface and Frame and project members	4/28/2017	4/28/2017	Go	2	0	Supported two people standing on table

DVP&R Frame

Report Date			Sponsor						Component/Assembly		2000	REPORTING ENGINEER: Kelsey		
TEST PLAN											**TEST REPORT**			
Item No	Specification or Clause Reference [1]	Test Description [2]	Acceptance Criteria [3]	Equipment Needed?	Test Responsibility [4]	Test Stage [5]	SAMPLES TESTED		TIMING		TEST RESULTS			NOTES
							Quantity	Type [6]	Start date	Finish date	Test Result [7]	Quantity Pass	Quantity Fail	
1	Belligerant User Testing	Rough housing with the frame to test strength and stability	Frame does not tip or break	A determined person		Complete	1	Raw Frame	2/4/2017	2/4/2017	Frame can withstand heavy loading but loading applied to the front causes it to tip	0	1	
2	Ease of manufacturing: Pin insertion	Drill holes for pins and test how well the pins withstand loading while remaining in place	Pins change position	A drill, a pin, a frame	Kelsey	Complete	2	Holes Drilled on Welded Frame	4/21/2017	4/21/2017	Table did not fit under drill press so holes must be drilled via a hand drill.	2	0	
3	Mobility tests	Assess how easily the frame is able to move on its own	Frame is able to easily maneuver around an area	A frame and a user	Kelsey	Complete	1	Full Frame	4/28/2017	4/28/2017	Frame is easy to move around	1	0	
4	Table wishbones under loading	Load table at angle (test improper loading)	Doesn't wishbone	A frame and a user	Kelsey	Complete	1	Two frames	6/2/2017	6/2/2017		1	0	Requires Second Table
5	Table doesn't nest	Attempt nesting	Nests	Two frames	Kelsey	Complete	1	Two frames	6/2/2017	6/2/2017	Frames Nested	1	0	Requires Second Table
6	Table doesn't unnest	Attempt unnesting	Unnests	Two frames	Kelsey	Complete	1	two frames	6/2/2017	6/2/2017	Frames Nested	1	0	Requires Second Table
7	Table (frame) is too heavy	Attempt to move and weigh frame	<50lb	A frame and a scale	Kelsey	Complete	1	Full Frame	5/2/2017	5/2/2017	25.4 lb	1	0	35.4 lb?

DVP&R Surfaces														
Report Date	6/5/2017		Sponsor	Harding						Component/Assembly		3000/4000	REPORTING ENGINEER: Kelsey	
TEST PLAN											TEST REPORT			
Item No	Specification or Clause Reference [1]	Test Description [2]	Acceptance Criteria [3]	Equipment Required	Test Responsibility [4]	Test Stage [5]	SAMPLES TESTED		TIMING		TEST RESULTS			NOTES
							Quantity	Type [6]	Start date	Finish date	Test Result [7]	Quantity Pass	Quantity Fail	
0	Surface pries apart too easily	Place a wedge in between the two sheets and attempt to pry apart	<25lb	Force reader and a wedge	Kelsey	Cancelled	Feature Removed							
1	Channel does not fit on edge of surface	Attempt to fit channel on edge of surface	Go/no go	Channel and surface	Kelsey	Complete	2	Go/no go	4/21/2017	4/21/2017	Go	2	0	Due to design change
2	Bushings fall out of holes	Attempt to press bushings out of the holes	<50lb	Bushings, surface and a force reader	Kelsey	Complete	1	Weight	6/4/2017	6/4/2017	No Go	0	2	5.38 lb to remove
3	Routing for edging	Route the edge of the surface to assure consistent alignment of the edging.	Ease of manufacturing assessment	A router and surface	Kelsey	Cancelled	Feature removed							
4	Round corners	Round the corners to a 2" radius	Ease of manufacturing assessment	Wood	Kelsey	Complete	2	Prototype surfaces	4/20/2017	4/20/2017	Complete	2	0	Plywood: 3:30, MDF: 2:00
5	Table has a heavy surface	Measure weight of surface, have others pick it up	<40lb	Scale and a surface	Kelsey	Complete	2	Prototype surfaces	5/1/2017	5/1/2017	17.3 (24" w/ channel) and 17.2 (25" w/o channel)	2	0	WEIGH TOP
6	Showerboard testing	Scratch testing of the	No scratching	Time and rough surfaces	Both	Complete	1	Sample sheets	2/28/2017	4/1/2017	Surface scratched	0	1	Design change made based on this testing

M Step By Step Test Instructions

M.1 Surfaces Tests

Listed in this section are the tests required to prove out the strength and manufacturability of the surfaces of the table. Unless stated otherwise, all records of testing should be recorded in the DVPR in Figure ??.

M.1.1 Channel Fit Test

1. Cut steel channel to length of longest flat edge of surface.
2. Place steel channel along the edge of the surface.
3. Record ease of testing.

To pass this test, the steel channel must be able to sit on the side of the table in order. If the channel does not fit on the side of the surface, the test will be counted as a failure.

M.1.2 Bushing Security Test

1. Insert bushings into properly sized holes in the surface.
   *Initial testing shall be performed with bushings press fit into place.
2. Attempt to pull bushings from holes using a force gage.
3. Record force required to remove bushing from hole if under 50 lb.
   * If bushings cannot be removed with a load of 50 lb or less, record this as well.

To pass this test, the bushings must remain in their holes with a 50 pound or lower load applied to them. If the bushings fall out of their holes with a load less than this amount, other methods should be used to secure the bushings in place. Method of bushing placement shall be modified until this load can be sustained.

M.1.3 Corner Rounding Test

1. Draw radius on each corner to follow when rounding the edges.
2. Use tools available in the shop to round the edges.
3. Record the time it takes to round the surfaces.

The time that it takes to round the corners of each surface shall be recorded.

M.1.4 Routing Test

1. With the corners of the table rounded, use the table router to route edge of the table for placement of the edging.
2. Record the time it takes to route the edge of the surface and any difficulties in manufacturing that may arise.

The time that it takes to route the edges of each surface shall be recorded as documentation of this test.

M.1.5 Surface Weight Test

1. Weigh completed surface.
2. Record the weight of the surface and any deviations of the surface from the drawings.

As per stated specifications, the surface must weigh less than 40 lb.

M.1.6 White Board Durability Test

1. Coat one side of work surface with white board coating.
2. Observe the durability of the coating with normal wear and tear.
3. Record any changes to the coated surface.

M.2 Frame Tests

Listed in this section are the tests required to prove out the strength and manufacturability of the frame of the table. Unless stated otherwise, all records of testing should be recorded in the DVPR in Figure **??**.

M.2.1 Belligerant User Testing

1. Allow a user to use the frame for methods that were not intended in the original design.
2. Record any damages which may occur to the frame.
3. Record any potential risks to the user.

The main purpose of this testing is to ensure that the frame does not tip or break when it is not used as intended.

M.2.2 Pin Insertion and Security Test

1. Drill holes for locating pins on the top surface of the frame.
2. Insert pins into holes.

   *Note, the pins will likely have an interference fit with the holes which will require some force to fit the pins in place. The use of a mallet will likely be required for secure insertion.
3. Record ease of insertion and any difficulties that arose when inserting the pins.

Pins should be securely located within the holes so that they do not ”wiggle”.

M.2.3 Mobility Test

1. Allow a user to move around an area with the frame.

   *The the testing should be encompass to check full mobility of the frame, including but not limited to its ability to fit through doorways and move from one area to another without disturbing its surrounding environment.
2. Record any difficulties that the user has with moving the frame.

For this test to be a success, the frame must be easy to maneuver around an area with only one user.

M.2.4 Load Wish-boning test

1. Apply a load on the outer corners of the frame to try to bend the frame out of shape.

   *Impact loading conditions, such as running the table into a wall may be considered at the discretion of facilities due to possible damage which may occur to property involved.

2. Record any changes to the shape which may occur.

After loading is applied, the frame should remain in its original shape, or within the specifications set forth in its drawings.

M.2.5 Nesting Test

1. With two frames completed and built to specifications, nest one frame within the other.
2. Record the time and perceived ease of nesting the two frames together.

Frames should easily nest together without an excessive amount of effort from the user.

M.2.6 Un-Nesting Test

1. Once the frames have been nested together, un-nest the frames.
2. Record the time and perceived ease of nesting the two frames together.

Frames should easily un-nest from each other without an excessive amount of effort from the user.

M.2.7 Frame Weight Test

1. Weigh the completed frame.
2. Record the weight of the frame and any deviations of the frame assembly from the drawings.

To pass this test, the frame must be under 50 lb. If the frame does not fall under this weight, the frame may require a redesign to fit this specification.

M.3 Overall Tests

Listed in this section are the tests required to prove out the strength and durability the full table assembly.

M.3.1 500 lb Distributed Loading Test

1. Set up table.
2. Set up barriers around the front and back edges of tables as seen in Figure M.1.

   *Large barriers should be used to diminish the effects of the table tipping, with this testing, this exact set up from this figure, though recommended, is not required.
3. Set up a ruler along the free hanging edge of the table.
4. Apply loads to the table in the order specified in Figure M.2 .

   *Loads should be distributed as evenly as possible over the surface of the table. Sand bags should be applied first, followed by the plate weights to follow the tabulated loads listed in Table **??**.

   **Loads should be administered from the angled sides of the table and feet should be kept 2 feet away from the surface of the table whenever possible to avoid injury in the event of the table top popping off, the table tipping or another unforeseen event occurring which could result in injury. Safety glasses are required for testing. Steel toed boots are highly recommended during this testing.
5. Record deflection that occurs to the table in Table **??** as each weight is placed. When unloading the table, record the deflections in Table N.3

Figure M.1: Set up configuration for table when doing heavy loading testing.

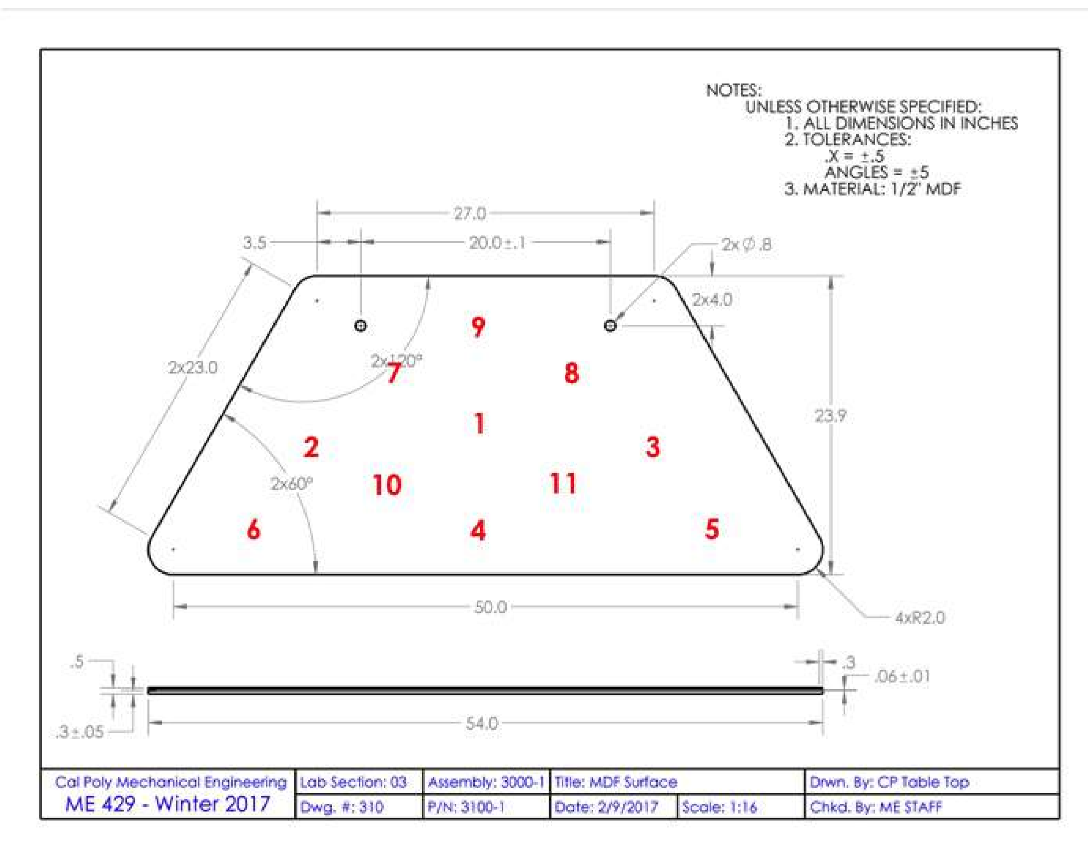


Figure M.2: Locations to load the plates to create a distributed loading.

If the table deflects over .25", tips, or breaks or the channel becomes separated form the latches in the process of this test, it will be considered to be a failure.

M.3.2 200 lb Point Loading Test

1. Set up table.
2. Set up barriers around the front and back edges of tables as seen in Figure M.1.

   *Large barriers should be used to diminish the effects of the table tipping, with this testing, this exact set up from this figure, though recommended, is not required.
3. Set up a ruler along the edge of the table where the clamp will be applied.
4. Attach a clamp to an extremity of the table at locations specified in Figure M.3.

   *Extremities of the table are considered to be the outer corners of the surface as well as the middle of the unsupported back side of the surface.
5. Apply a load to the clamp via a rope secured to.

   *When applying a load to the clamp, a 2-foot radius should be kept between the tester and the table whenever possible to avoid injury in the event of the table top popping off, the table tipping or another unforeseen event occurring which could result in injury. Safety glasses are required for testing. Steel toed boots are highly recommended during this testing.
6. Record deflection that occurs to the table in Table N.2

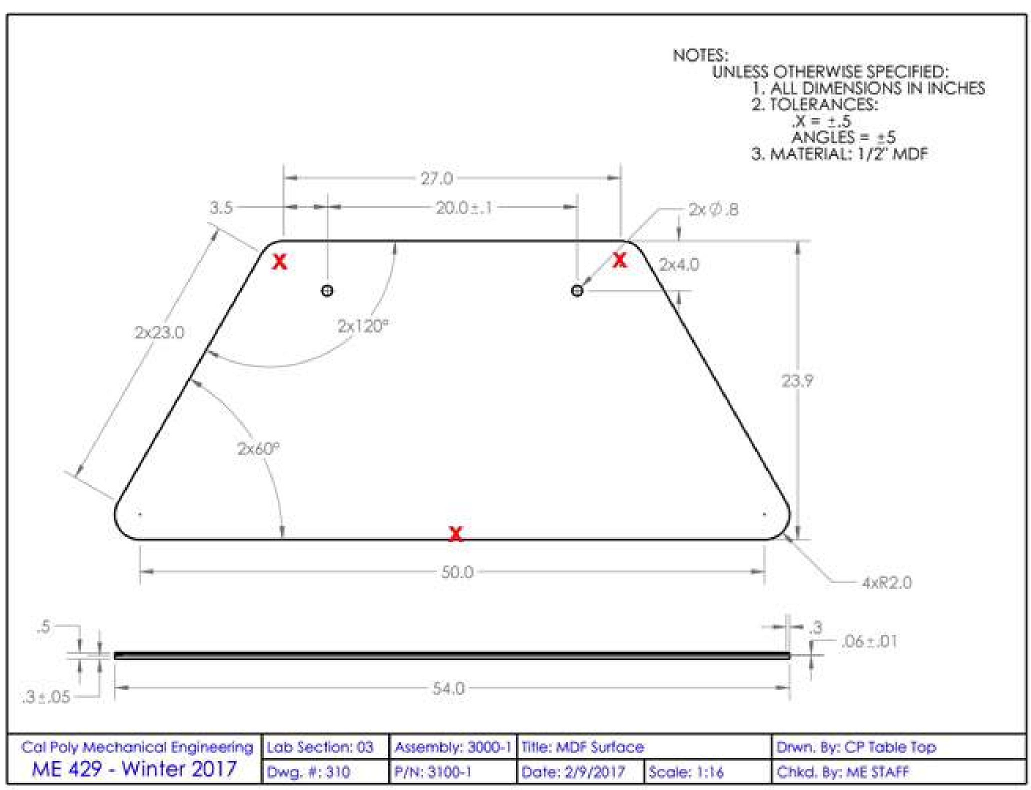


Figure M.3: Locations to attach the clamp to create a point loading.

If the table deflects over .25", tips, or breaks or the channel becomes separated form the latches in the process of this test, it will be considered to be a failure.

M.3.3 Small Distributed Loading Tests Over a Given Area

1. Set up table.
2. Set up barriers around the front and back edges of tables as seen in Figure M.1.

   *Large barriers should be used to diminish the effects of the table tipping, with this testing, this exact set up from this figure, though recommended, is not required.
3. Load weights over areas specified in Figure M.3.

   *Weights should be via sand bags to simulate a person sitting on the areas deemed as "weak points".
4. Record deflection that occurs to the table in Table N.3

If the table deflects over .25", tips, or breaks or the channel becomes separated form the latches in the process of this test, it will be considered to be a failure.

M.3.4 Shake Test

1. Set up table.
2. Place mixer on the table.
3. Create clay cone. Measure initial height of cone.
4. Place table so that it touches the edge of the clay cone.
5. Turn on mixer at speeds specified in Table N.6
6. Record deflection that occurs to the cone in Table N.6

   *The cone may need to be reshaped between tests.

If the table deflects over .125", the test will be considered a failure.

M.3.5 Human Loading Test

1. Set up table.
2. Have users lean on the table.

3. Record deflection of the table in Table N.5.

If the table deflects over .125”, slides, tips, or breaks or the channel becomes separated form the latches in the process of this test, it will be considered to be a failure.

M.3.6 Set Up Tests

1. Bring in volunteers, record their height.
2. Without instruction, have volunteer set up table.
3. Record time it takes to set up the table in Table N.1.
4. Repeat steps 2-5 twice.
5. Calculate average set up time.

If it takes a user longer than 60 seconds to set up or longer than 30 seconds to take down the table, this test will be considered a failure. If any features of the table are clearly causing problems with lining up the pins, record this as well.

M.3.7 Wheel Mobility Test

1. Set up table
2. Attempt to roll full table around an area.

   *Different surfaces should be tested in this process including but not limited to: carpet, tile, and concrete.
3. Record any difficulties which may occur with the wheels.

The table should be able to easily maneuver different terrain. If it cannot, this test will be considered a failure.

M.3.8 Durability Test

1. Set up table.
2. Have determined volunteers attempt to break the table.
3. Record any changes which occur to the table.

If the table horizontally deflects over .125", vertically deflects over .25", slides, tips, or breaks or the channel becomes separated form the latches in the process of this test, it will be considered to be a failure.

M.3.9 Surface Removal Test

1. Set up table.
2. Use force gage to measure the force required to remove the surface from the frame
3. Record the force required in Table N.7.

N Test Documentation Sheets

Table N.1: Measurements of the time it takes to line up the holes with the pins on the final table.

Subject Information		Pin Alignment Time [s]			
Student	Height (ft-in)	1	2	3	Average
Chris	5'-8"	5.56	6.35	7.17	6.36
Eric	6'-2"	18.29	8.94	14.12	13.78
Jay	5'-10"	8.72	7.38	10.73	8.94
Daniel	6'-7"	7.73	6.62	5.56	6.50
Amy	5'-4"	26.18	8.37	6.58	13.71
Averages		13.30	7.45	8.83	9.86

Table N.2: Deflection under a vertical point load with increasing weight being applied to the final formal surface.

Current Point Load [lb]	**Front Right Corner [in]**	**Front Left Corner [in]**
5	0	1/8
10	0	1/8
15	1/8	Failed. Surface Popped Off
20	1/8	-
25	1/8	-
30	1/8	-
35	3/16	-
40	1/8	-
45	Failed. Surface Popped Off	-

Table N.3: Deflection under distributed vertical loading with weights being removed on the table.

Current Point Load [lb]	**Deflection [in]**
589.9	9/16
541.7	9/16
490.1	17/32
441.6	1/2
390.7	7/16
339.4	11/32
286.3	5/16
235	5/16
165	1/8
135	1/8
90	1/16
45	0
0	0

Table N.4: Observations of table behavior under wide ”point” loading conditions.

Location	**Total Load [lb]**	**Comments**
Unsupported Edge	51.3	Stable
	104.4	Stable
	156.0	Stable
	207.6	Deflection of 1 3/8 in
Front Left Corner	51.3	Stable
	104.4	Stable
	152.9	Still stable
	204.4	Still stable
	252.4	Still stable, magnets active
	303.3	Still stable
Front Left Corner	51.3	Stable, back left cap off of ground
	102.6	Stable
	155.7	Stable
	203.9	Slight wobbling
	252.4	Magnets active
	303.3	Magnets active

Table N.5: Deflection under a lateral load.

Subject Information		Did the table slip?	Comments
Student	**Height [ft-in]**	**[Yes/No]**	
Drew Whitney	6'-1"	No	Leaning on sides
Kelsey Ishimatsu Jacobson	5'-3"	No	Leaning on sides
Jesse Lutz	5'-9"	Yes	On front, legs raise and tip
Joe McGill	5'-10"	No	Leaning on sides
Drew Whitney	6'-1"	Yes	Leaning on front edge tips the table, leaning on back edge causes table to rotate

Table N.6: "Eraser Test" – How much deflection occurs when the table is shaken using a stand mixer with a 2.5 lb weight attached to the paddle?

Mixer Setting	Deflection [in]
Stir	1/32
2	1/4
4	Weight detached from paddle. Test cancelled.

Table N.7: Top Removal Test: How much force is required to remove the table top?

Location	Trial 1 [lb]	Trial 2 [lb]	Trial 3 [lb]
Front Center	22	n/a	n/a
Right Side	6.88	7.02	6.94
Left Side	12.22	5.32	9.22
Back Right	11.41	10.97	11.20
Back Left	7.94	8.26	10.21

O Gantt chart

This appendix details the timing of this project through a Gantt Chart.

ID		Task Mode	Task Name	Duration	Start	Finish	Actual Start	Actual Finish
1			**Design**	**96 days**	**9/29**	**2/9**	**NA**	**NA**
2			**Ideation**	**33 days**	**9/29**	**11/14**	**NA**	**NA**
3			Background Research	12 days	9/29	10/14	NA	NA
4			**Large Scale Prototyping**	**7 days**	**11/4**	**11/14**	**NA**	**NA**
5			Materials Gathering	1 day	11/4	11/4	NA	NA
6			In Shop Protyping	7 days	11/5	11/14	NA	NA
7			**Project Proposal**	**13 days**	**10/10**	**10/26**	**NA**	**NA**
8			Outline	1 day	10/10	10/10	NA	NA
9			Update	1 day	10/11	10/11	NA	NA
10			First Draft	9 days	10/12	10/23	NA	NA
11			Review	3 days	10/23	10/25	NA	NA
12			Submit	1 day	10/26	10/26	NA	NA
13			**Preliminary Design Review**	**11 days**	**11/3**	**11/17**	**NA**	**NA**
14			Outline	1 day	11/5	11/5	NA	NA
15			Update Sections from PP	3 days	11/3	11/5	NA	NA
16			First Draft	4 days	11/7	11/10	NA	NA
17			Review/Finalize	3 days	11/11	11/15	NA	NA

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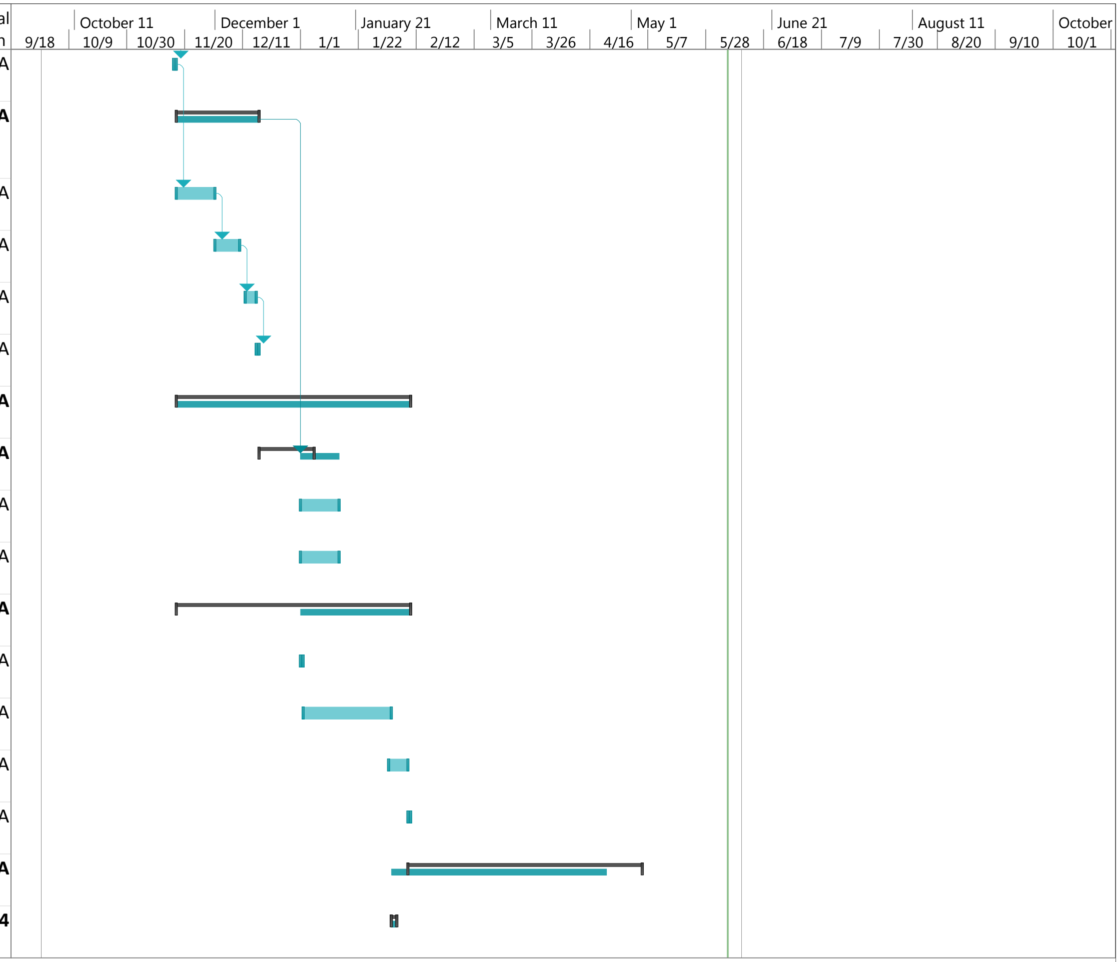
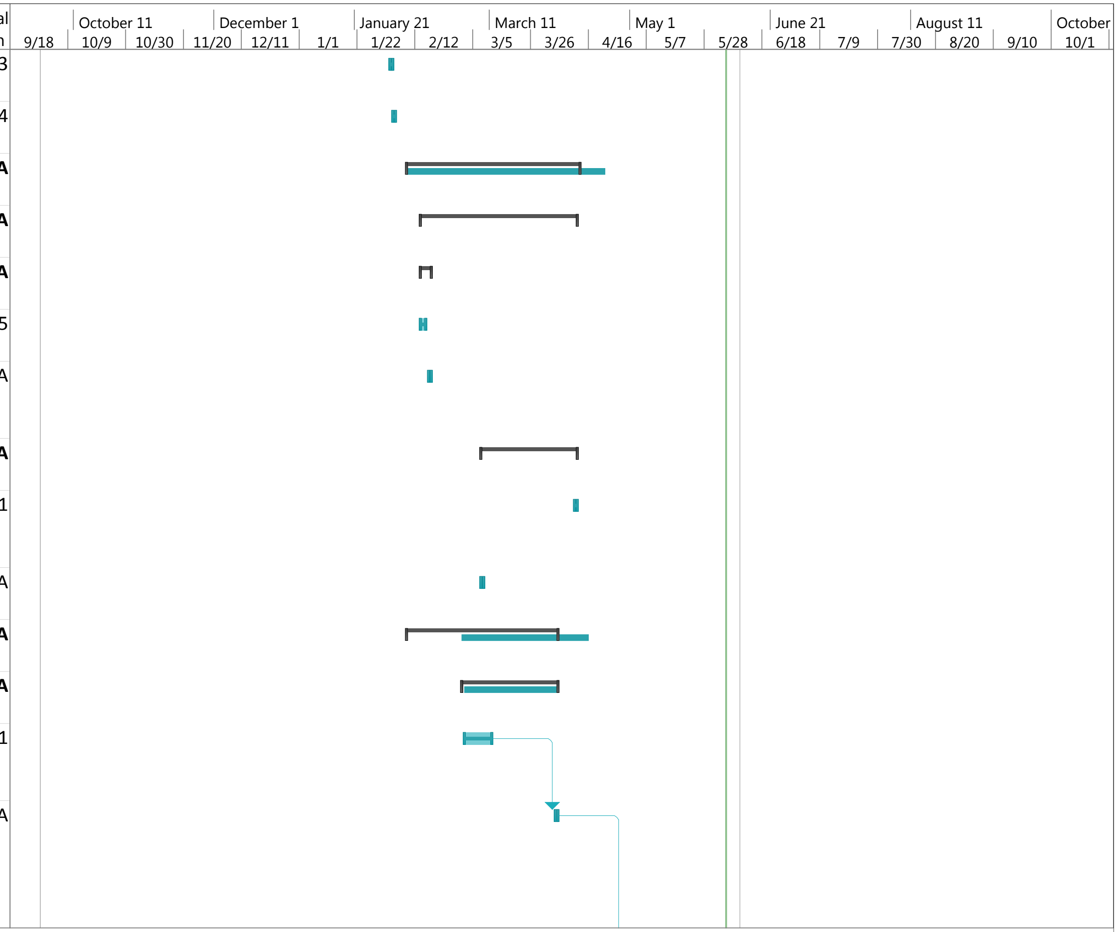
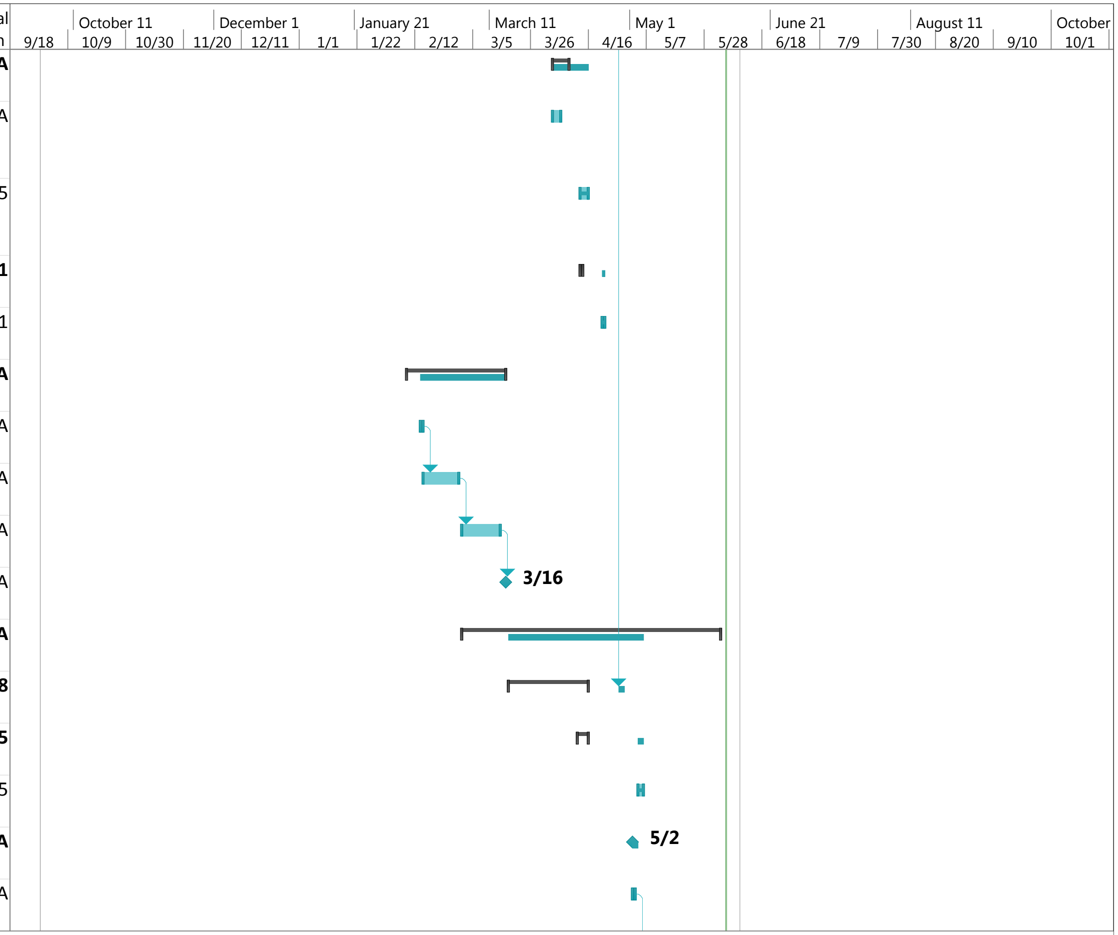
ID		Task Mode	Task Name	Duration	Start	Finish	Actual Start	Actual Finish
18			Submit	1 day	11/16	11/16	NA	NA
19			**Preliminary Design Review Review**	**22 days**	**11/17**	**12/16**	**NA**	**NA**
20			Receive Input	10 days	11/17	11/30	NA	NA
21			Review Input	7 days	12/1	12/9	NA	NA
22			Rewrite	4 days	12/12	12/15	NA	NA
23			Resubmit	1 day	12/16	12/16	NA	NA
24			**Critical Design Review**	**61 days**	**11/17**	**2/9**	**NA**	**NA**
25			**Finalize Design**	**14 days**	**12/16**	**1/5**	**NA**	**NA**
26			Hand Calcs	12 days	1/1	1/14	NA	NA
27			Complete CAD	12 days	1/1	1/14	NA	NA
28			**Report**	**61 days**	**11/17**	**2/9**	**NA**	**NA**
29			Outline	1 day	1/1	1/1	NA	NA
30			First Draft	24 days	1/2	2/2	NA	NA
31			Review	5 days	2/2	2/8	NA	NA
32			Submit	1 day	2/9	2/9	NA	NA
33			**Build**	**62 days**	**2/9**	**5/4**	**2/3**	**NA**
34			**Manufacture Frame**	**2 days**	**2/3**	**2/4**	**2/3**	**2/4**



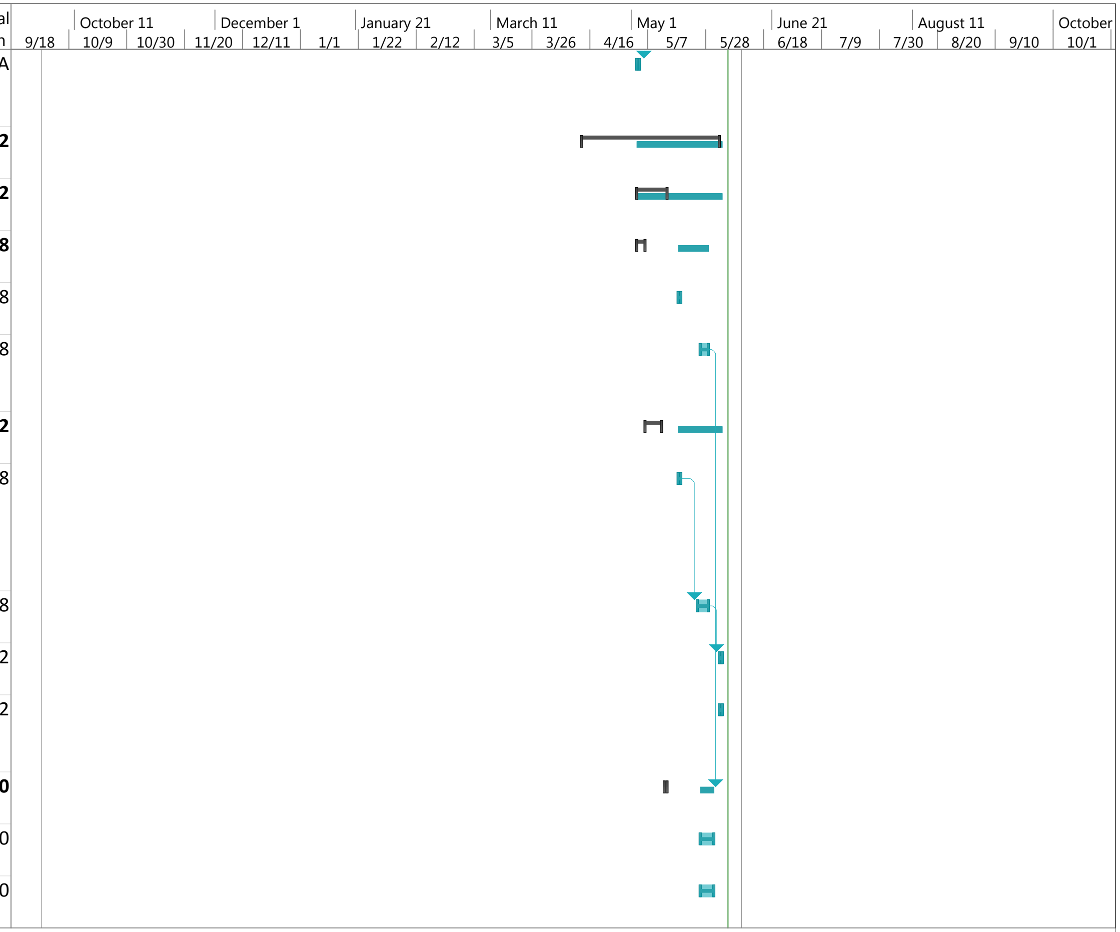
ID	Indicators	Task Mode	Task Name	Duration	Start	Finish	Actual Start	Actual Finish
35	✓		Acquire Materials	1 day	2/3	2/3	2/3	2/3
36	✓		Build Frame	1 day	2/4	2/4	2/4	2/4
37			**Maufacture Model**	**46 days**	**2/9**	**4/12**	**2/14**	**NA**
38			**Acquire Materials**	**42 days**	**2/14**	**4/11**	**2/14**	**NA**
39			**Preliminary Purchases**	**4 days**	**2/14**	**2/17**	**2/14**	**NA**
40	✓		Order Materials	2 days	2/14	2/15	2/14	2/15
41			Acquire Local Materials	1 day	2/16	2/17	2/16	NA
42			**Later Purchases**	**25 days**	**3/7**	**4/11**	**3/7**	**NA**
43	✓		Purchase Full Sheets	1 day	4/11	4/11	4/11	4/11
44			Order Channel	1 day	3/7	3/8	3/7	NA
45			**Prototype Surfaces**	**40 days**	**2/9**	**4/4**	**3/2**	**NA**
46			**Small Surfaces**	**25 days**	**3/1**	**4/4**	**3/2**	**NA**
47	✓		Laminate Small Surfaces	8 days	3/2	3/11	3/2	3/11
48			Cut and Finish Surfaces (if desired)	1 day	4/4	4/4	NA	NA



ID		Task Mode	Task Name	Duration	Start	Finish	Actual Start	Actual Finish
49			**Full Sized Surfaces**	**6 days**	**4/3**	**4/8**	**4/3**	**NA**
50			Laminate Full Sheets	3 days	4/3	4/5	NA	NA
51			Cut and Finish Surfaces	3 days	4/13	4/15	4/13	4/15
52			**Modify Current Model**	**1 day**	**4/13**	**4/13**	**4/21**	**4/21**
53			Attach New Components	1 day	4/21	4/21	4/21	4/21
54			**Manufacturing & Test Review**	**27 days**	**2/9**	**3/16**	**NA**	**NA**
55			Outline	1 day	2/14	2/14	NA	NA
56			First Draft	10 days	2/15	2/27	NA	NA
57			Revise	10 days	3/1	3/14	NA	NA
58			Report Due	0 days	3/16	3/16	NA	NA
59			**Test**	**68 days**	**3/1**	**6/2**	**3/18**	**NA**
60			**Small Surface Tests**	**22 days**	**3/18**	**4/15**	**4/27**	**4/28**
63			**First Prototype Test**	**4 days**	**4/12**	**4/15**	**5/4**	**5/5**
64			Testing All Loading Cases	2 days	5/4	5/5	5/4	5/5
65			**Hardware Review**	**0 days**	**5/2**	**5/2**	**NA**	**NA**
66			Meeting with advisor	1 day	5/2	5/2	NA	NA



ID		Task Mode	Task Name	Duration	Start	Finish	Actual Start	Actual Finish
67			Approval to Build Second Model	1 day	5/3	5/3	NA	NA
68	✓		**Second Model**	**36 days**	**4/13**	**6/1**	**5/18**	**6/2**
69	✓		**Build Table 2**	**9 days**	**5/3**	**5/13**	**5/18**	**6/2**
70	✓		**Acquire Materials**	**3 days**	**5/3**	**5/5**	**5/18**	**5/28**
71	✓		Purchase Steel	1 day	5/18	5/18	5/18	5/18
72	✓		Home Depot Purchase	2 days	5/26	5/28	5/26	5/28
73	✓		**Build Frame**	**5 days**	**5/6**	**5/11**	**5/18**	**6/2**
74	✓		Cut Steel and Drill All Holes for Attachment Components	1 day	5/18	5/18	5/18	5/18
75	✓		Weld Steel	3 days	5/25	5/28	5/25	5/28
76	✓		Attach Components	1 day	6/2	6/2	6/2	6/2
77	✓		Check Fit of MDF Surfaces	1 day	6/2	6/2	6/2	6/2
78	✓		**Build Surfaces**	**1 day**	**5/13**	**5/13**	**5/26**	**5/30**
79	✓		MDF Surfaces	3 days	5/26	5/30	5/26	5/30
80	✓		Plywood Surfaces	3 days	5/26	5/30	5/26	5/30



ID	Info	Task Mode	Task Name	Duration	Start	Finish	Actual Start	Actual Finish
81			**Project Expo**	**0 days**	**6/2**	**6/2**	**NA**	**NA**
82			Senior Project Expo	0 days	6/2	6/2	NA	NA
83			**Everything Complete**	**6 days**	**6/2**	**6/9**	**NA**	**NA**